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The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, narrow insularity is avoided by publishing a number of articles from overseas contributors and by impartial reference to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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Carl Friedrich Gauss (1777–1854)

It is related that Laplace was once asked by Baron von Humboldt who, in his opinion, was the greatest mathematician in Germany. The reply not being what von Humboldt had hoped for, he asked 'But what about Gauss?', for he was at that time endeavouring to obtain the appointment of Gauss to the post of director of the Göttingen Observatory. 'Gauss?' answered Laplace. 'He is the greatest mathematician in the world!'

This was high praise of a young man who at that time was only 29 years of age, but subsequent events proved how correct Laplace was in his assessment. For Gauss became known as *mathematicorum princeps*, and he must be placed second only to Newton among the great mathematicians. There is a similarity between the two men in the early flowering of their genius, in the wide range of their discoveries, and in their mode of thought.

From a very early age Gauss showed a precocity in mental numerical calculation. Throughout his life he retained a prodigious power for mental calculation and a love of complicated numerical computation. It is said that he never had any need to refer to tables of logarithms. It is not surprising, therefore, that arithmetic and the theory of numbers became his favourite studies.

The first of his great masterpieces, the *Disquisitiones Arithmeticae*, was completed in 1798, when he was only 21 years of age, though the Leipzig printer's difficulties caused publication to be delayed until 1801. This work welded the theory of numbers, which previously had comprised a number of unrelated theorems, into a coherent and logical discipline and gave it a new direction. It is difficult reading, even for experts in the subject, for Gauss aspired to a classic perfection of style, and the line of reasoning by which he was led to his results is not apparent. It treats, among other matters, of the theories of congruences (and in particular of binomial congruences), of quadratic residues, and of binary and ternary quadratic forms. Some regard it as the greatest of his works; it was an amazing production for one so young.

The discovery by Piazzi at Palermo, on 1st January 1801, of the first of the asteroids, Ceres, presented Gauss with a problem that drew his attention for a time away from the higher arithmetic. Ceres could be observed only for a few weeks before it was lost to view. Unless its orbit could be computed there was a probability that it would not be rediscovered. In theory, three observations of the position of a planet or comet suffice to determine its orbit, but the problem of deriving an orbit from a short arc had never before arisen. Gauss developed a method of solution, calculated the orbit of Ceres, and correctly predicted where it would be found. The method used was extended into a thorough discussion of methods of determining planetary and cometary orbits, including the analysis of perturbations, and was published in 1809 under the title *Theoria motus corporum coelestium in sectionibus conicis solem ambientium*; the methods used today are essentially based upon it.

But the whole of his energies was not absorbed by these problems. He was the first to give a coherent account of complex numbers and to interpret them as labelling points on a plane; he enunciated in a letter to Bessel the fundamental theorem in what is now called the analytic functions of a complex variable, a result which he did not publish and which was later rediscovered by Cauchy; and he proved that every numerical equation has a real or imaginary root.

Another great work was on the hypergeometric series. Infinite series had been used by mathematicians without any examination of the conditions under which they are convergent. Gauss determined the conditions for the convergence of the hypergeometric series, which as special cases include many of the important series in analysis. For the first time, he imposed rigour on analysis, and thereby revolutionized its methods.

The important memoir on biquadratic reciprocity broke entirely new ground. Here were introduced what are now termed the Gaussian complex integers, thereby bringing complex numbers for the first time into the theory of numbers and inaugurating a general theory of algebraic numbers.

The appointment of Gauss as scientific adviser to the Danish and Hanoverian governments in connection with an extensive scheme of triangulation, including the measurement of an arc of meridian, not only provided him with scope for dealing with extensive masses of numerical data but renewed his interest in the theory of errors and the adjustment of observations. He had invented the method of least squares when he was 18. This method, based on the Gaussian law of distribution of random errors, is extensively used in all branches of science, and especially in astronomy and geodesy. Two important memoirs, *Über Gegenstände der höhern Geodäsie*, appeared in 1843 and 1846

respectively. The memoir on *Theoria combinationis observationum erroribus minimis obnoxia* had appeared earlier. The surface of the Earth being curved, Gauss was led to consider the general problems connected with curved surfaces, such as the properties of geodesics and the definition of curvature. He introduced the parametric representation of surfaces, which is independent of extraneous axes, and thereby laid the foundations of differential geometry. He developed the method of conformal mapping in which angles are preserved, using the theory of analytic functions of a complex variable.

About 1830 Gauss began to take an interest in the problems of the Earth's magnetism. With Weber he invented the declinometer and the bifilar magnetometer. In 1833 appeared the memoir *Intensitas vis Magneticae Terrestris ad Mensuram Absolutam Revocata.* He erected a magnetic observatory in Göttingen for the study of the changes of the Earth's magnetism and formed a Magnetic Association for obtaining observations at prearranged days at a number of stations. Two important memoirs, *Allgemeine Theorie des Erdmagnetismus* and the *Allgemeine Lehrsätze*, appeared in 1838 and 1839; these included the harmonic analysis of the Earth's magnetic field and a general theory of forces attracting according to the inverse square of the distance. Very appropriately, the unit of magnetic intensity is named the gauss.

Another important memoir, *Dioptrische Untersuchungen*, published in 1840, gave a general theory of optical systems, to permit of the determination of the image of any object in any system. This memoir introduced the conception of the six cardinal points, the two focal points, the two nodal points, and the two principal points, which are often called the Gaussian points.

Limitations of space prevent reference being made to all of Gauss's work, for he made important contributions to almost every branch of mathematics. The subject of non-Euclidean geometry began with him. While still at school he had felt the need to examine the postulates of Euclidean geometry and had found that a geometry could be developed without the postulate of parallels. He subsequently showed that perfectly self-consistent results could be obtained without it. The theory of determinants, the calculus of variations, and the theory of elliptic functions were other subjects to which he contributed.

It is amazing that one man could make contributions of such importance and of such originality to so many different subjects. It was indifferent to Gauss whether he was working in pure or in applied mathematics. Every subject that he touched he adorned. He developed new branches of mathematics, and to others he gave a new direction and a new stimulus.

In memoriam: Sir Wallace Akers (1888–1954)

With profound regret we record the death on 1st November, 1954, of Sir Wallace Akers, who was a member of the editorial advisory panel of ENDEAVOUR until ill-health necessitated his retirement last year. His death will be felt as a personal loss by all concerned with the publication of ENDEAVOUR, for despite the eminence to which he attained he remained the most approachable of men. Those who sought his advice always found wise counsel, and were made to feel that the problem to be discussed, whether trivial or otherwise, was absorbing his whole attention. A good listener when the occasion called for it, he was also a great conversationalist. On the editorial advisory panel his capacity of dealing with equal facility with points of detail and points of general principle was invaluable.

Sir Wallace Akers was born on 9th September, 1888, and was educated at Aldenham School and at Christ Church, Oxford. From the University of Oxford, which conferred an honorary degree upon him in 1952, he went straight into the chemical industry, with which he was closely associated virtually all his life. From Oxford, in 1911, he joined Brunner, Mond and Company Limited, one of the founding companies of Imperial Chemical Industries Limited. Apart from a brief period spent in the Far East, and a short time as director of British atomic energy research, the whole of the rest of his working life was spent with Imperial Chemical Industries, of which he became a director in 1941. In that year he was seconded to the Department of Scientific and Industrial Research to take charge of the British atomic energy project. In this capacity he did work of great national importance, for which he was knighted. He retired in 1953, but for him retirement implied a direction of his energies into new channels rather than any diminution of them, and his death is a very great loss to science and to the public service. He was known throughout the world not only as an eminent scientist but as a most lovable man.

The riddle of influenza virus

SIR MACFARLANE BURNET

Growing knowledge of the influenza virus leads to the conclusion that while this has distinct antigenic, enzymic, and genetic properties, it is at the same time chemically indistinguishable from fragments of the cytoplasm of the cells in which it is a parasite. This conclusion is of fundamental importance, not only in devising new methods of attacking what can be a very deadly disease but for understanding the structure and function of the vertebrate cell.

For the last ten or twelve years influenza virus has been a favourite object of study for those who are interested primarily in the nature of viruses rather than in the diseases for which they are responsible. This virus has two qualities which make it particularly suitable for such studies. The first is that it can be grown very readily in the cavities of the chick embryo, the allantoic fluid of which then provides a relatively concentrated and conveniently handled form of virus. A second, and even greater, advantage to the experimenter is that the concentration of virus in such fluids can be accurately and simply titrated in the test-tube by utilizing the virus's power of agglutinating red blood cells—the haemagglutination phenomenon of G. K. Hirst.

These properties facilitate investigations necessary to establish the physico-chemical nature of the virus particles and to determine, at least in outline, the course of their multiplication in the cell. These investigations have in fact been made, and at least as much is now known about the nature and activities of a typical influenza virus, such as the standard American strain PR8, as about any other animal virus. As this knowledge accumulated, there gradually became clear the paradox with which this article is concerned—that although the particles of influenza virus are well-defined, functional units with characteristic antigenic, enzymic, and genetic qualities, chemically they cannot be differentiated from fragments of the cytoplasm of the cells in which they are parasites.

THE FUNCTIONAL ACTIVITIES OF THE VIRUS PARTICLE

Influenza viruses are nowadays defined, and even named, on the basis of their reaction with vertebrate red blood cells, a reaction normally manifested as haemagglutination; the virus particles themselves are the agglutinating agents. When virus, in the form of allantoic fluid from an infected chick embryo, is mixed with a red-cell suspension, the virus particles stick firmly to the cell surfaces; since one virus particle can, if conditions are suitable, be adsorbed simultaneously by two cell surfaces, a whole series of bridges between the red cells is rapidly developed. The cells become tied together into visible aggregates, which rapidly clump. With a concentrated virus such a suspension is very quickly converted into a clear supernatant fluid and a mass of agglutinated cells, the latter often producing rather characteristic patterns by adhesion of the altered cells to the hemispherical bottom of the test-tube. This condition is, however, not permanent. If the mixture is kept at 37° C, and is reshaken every thirty minutes, it will be found that the cells take progressively longer to settle and that the clumps are smaller. After two or three hours, the cells may become as stable in suspension as normal cells. Experiment shows that the virus has been released from the cells, which have lost all their capacity to adsorb, or to be agglutinated by, the virus.

Study of this phenomenon has shown that it is the result of a specific interaction between components of both the virus surface and the cell surface. The interaction has most of the characteristics of enzyme action, and can best be regarded as an unusually slow type of action of this kind, in which the intermediate union of enzyme and substrate, postulated for all enzyme actions, is a conspicuous feature.

In 1947 the substrate of the virus enzyme was identified as a mucoprotein, and all subsequent work has confirmed this opinion. Several mucoprotein substrates of influenza virus enzyme have now been prepared in pure form, the degree of purity being judged by the very rigid tests of the production of a single peak in the electrophoresis pattern and a shift of the peak as a whole (indicating a lower electrophoretic mobility of the

component) when the preparation is treated enzymically with the virus. Gottschalk has recently made some noteworthy advances in isolating and characterizing the split product resulting from the reaction and in defining the probable nature of the prosthetic group with which the virus enzyme reacts. This, however, is not relevant to our immediate theme, which is the specificity of reaction of the influenza viruses. In the field of adsorptive-enzymic reactions this specificity is best shown in the phenomena of the receptor gradient.

THE RECEPTOR GRADIENT

The simplest way of demonstrating the nature of a receptor gradient is to take a suspension of washed human red cells and to treat portions of it with the enzyme prepared from filtrates of *V. cholerae* cultures, an enzyme which Burnet and Stone [1] have called RDE (receptor-destroying enzyme). This enzyme appears to be isodynamic with the enzymes of the viruses of the influenza group. By the graded action of the enzyme one can prepare a series of cell suspensions which are progressively less readily agglutinated by viruses. If a comprehensive series of viruses is tested for power to agglutinate these cells, they will be found to fall into linear order. Newcastle disease virus (NDV) is the first to lose its power to agglutinate, and, in our standard series, the influenza B strain MIL is the last. Parallel to the loss of agglutinability there is a progressive fall in the electrophoretic mobility (EPM) of the cells, and Ada and Stone [2] have shown that the point at which agglutinability by each virus is lost can be defined in terms of the EPM of the cells.

Without going into further detail, it can be said that by these techniques it is possible to demonstrate a specific and reproducible characteristic of each strain of influenza virus. The favoured interpretation is that the actual enzymic group is common to all the viruses and to RDE, but that for each virus there is a characteristic pattern of atomic groups surrounding each enzymic unit and modifying the ease with which contact with substrate groups, of varying degrees of accessibility, may be made. The regularity of the results implies that these patterns have some individual specificity for each type of virus.

ANTIGENIC CHARACTER

Uncomplicated influenza is a self-limiting disease, which is probably brought to an end by the development of active immunity, marked by the appearance in the blood of neutralizing antibody that can be experimentally detected. No one has two attacks of the same kind of influenza in a single epidemic, and the whole modern approach to the epidemiology of influenza is based on recognition of the immunological character of the strains of virus which are responsible for successive epidemics. The most practical approach to the study of these differences is by the use of anti-haemagglutinin (AHA) titrations. If to a series of dilutions of convalescent serum—obtained from a human patient or an infected ferret—a standard amount of virus is added, the power of the virus to agglutinate red cells is destroyed by all concentrations of serum above a certain minimum. This allows one to express quantitatively, as its AHA titre, the power of the serum to inactivate any given influenza virus. There are important technical precautions needed to avoid confusion with some types of non-specific inhibition of haemagglutination, but if these are taken it is possible to obtain a clear pattern of antigenic relationships between the various types of influenza virus that have appeared and been isolated since 1933. The most important study of this type, due to Hirst [3], shows that seven specific antigens successively appeared in influenza A strains between 1933 and 1951. In addition, there are antigenic factors that are common to some or all types. Occasionally a strain may change its antigenic character in the laboratory, usually as a result of transfer to a new host. However, if strains are maintained solely by chick-embryo passage they remain constant in their immunological behaviour. Since such precautions have been taken it has been found that, in any given year in which influenza has been widely prevalent throughout the world, only one, or at most two, antigenic types of virus have been involved.

The antigenic specificity of the virus is, then, a well-defined, functional character of vital importance for both the survival of the virus in nature and the epidemiologist's understanding of the disease it causes. Since antibody can be removed from a serum by treating it with large amounts of influenza virus, the antigens concerned must lie on the surface of the virus. They have not been isolated as pure chemical substances, but by every analogy with other phenomena in the same class they must be protein molecules possessing an individual pattern of atomic configuration that serves as the antigenic determinant. These patterns are quite distinct from any such patterns in the proteins of the host species and also from the protein patterns of serologically

distinct influenza viruses. It is not possible to say whether or not they are related to the complex of enzyme and associated groupings that are concerned in the phenomena of the receptor gradient.

GENETIC INDIVIDUALITY

All the characteristics of influenza viruses which are reproducible from generation to generation must necessarily have a genetic basis. The systematic study of genetic characters in animal viruses has, however, only recently been undertaken. Such work becomes possible when we have available a means for isolating and maintaining pure clones of virus; a series of conveniently demonstrable genetic markers, by which pure clones of different hereditary constitution can be characterized; and a technique by which genetic interaction between two different strains can be allowed to occur. These requirements have been fulfilled for some time in regard to the bacterial viruses, and a major activity of the writer's own laboratory has been to develop a similar approach to the influenza viruses. We believe that we now have adequate technical methods for demonstrating that a number of well-marked genetic interactions can take place between influenza virus strains. In the system that we have studied most intensively—namely the interactions of various substrains of the classical influenza A strains, WS (Hampstead 1933), and MEL (Melbourne 1935)—the results indicate far-reaching recombination involving two distinct linkage groups. Four 'markers', i.e. differences between strains, are located in one linkage group, three others in the second. Without attempting to go into detail, which may be found in papers by Burnet and Lind since 1951 [4], the type of result may be indicated as follows. If we call the markers of MEL strain A, B, D, F and C, E, G respectively, and those of the neurotropic variant of WS a, b′, d, f and c, e, g, the following recombinations have been obtained:

ABDF: ceg	ABDF: ceG	ab′df: cEG
abdf: CEG	abdf: ceg	aB′df: cEg

Each of these represents a true-breeding type available in the form of a pure clone. Rather different rules hold in regard to the transmission of virulence when recombination occurs between a highly virulent and a non-virulent strain. It is usual to find among the progeny strains at any one of several intermediate degrees of virulence, with or without interchange of other 'marker' qualities.

Here, however, there is no need to discuss the details of influenza virus genetics. All that is needed is to make clear the existence in influenza virus of a complex genetic mechanism, which we consider to show fairly clear analogies with the genetics of bacterial viruses on one hand and with the genetics of bacteria on the other. Qualities can be transferred as units which behave in all essentials like the genes in higher organisms. Experience with influenza virus would lead one to postulate not less than twenty genes per virus genome. In addition there is cogent evidence that each morphological virus particle may have one, two, three, or more genomes, perhaps with two as the usual average.

These genetic qualities must have a physical basis, presumably a molecular pattern in nucleic acid. The most recent work, by Ada, on the nucleic acid content of purified influenza virus indicates that there is no deoxyribonucleic acid (DNA) present as an integral part of the influenza virus particle; the genetic behaviour must therefore depend on the 0·8 per cent of ribonucleic acid (RNA) known to be present. This, incidentally, gives a greatly increased importance to these genetic studies of influenza virus, since they relate to the only known system, capable of genetic analysis, in which deoxyribonucleic acid can play no part.

To summarize, we have in the viable influenza virus particle a complex, well-defined system. Each type has its own functional characteristics, which can be defined in terms of the interaction of virus with cell surfaces and with the specific mucoproteins that serve as substrate for the interactions; of the antigenic qualities of the virus; and of the virulence of the strain towards different cells and organs. With some qualifications in regard to virulence, all these characters are maintained on passage, under optimal conditions, in the allantoic cavity. Again with some minor qualifications, differences between related strains can be shown to be determined by genetic units of the same general quality as the genes of higher organisms. We can, then, be quite dogmatic in classing the influenza virus as an organism with elaborate patterns of functional activity similar to those of other organisms. With this conclusion in mind we can examine the physical nature of this functioning organism.

THE PHYSICAL QUALITIES OF INFLUENZA VIRUS

The virus particles can readily be separated from infected allantoic fluid by fractionation in the ultracentrifuge and by repeated washing;

their morphology can be examined under the electron microscope (figure 1) after fixation and shadowing by the conventional techniques. With well adapted stock-strains most of the particles appear in more or less spherical form, some being flatter than others. Their mean diameter is around 110 mμ, with a fairly wide scatter of individual values. In addition, one always sees rodlets, apparently made up of from two to four fused spheres. The spherical units themselves are by no means uniform in diameter, and a careful examination of a good electron micrograph impresses one with the reasonableness of the conclusion, based on genetic evidence, that particles may carry one, two, or three sets of genetic units. The range of sizes could well represent masses ranging from one to three arbitrary units. In these old stock-strains the long filaments which are such a feature of recent strains are absent or very rare.

The evidence that the spheres we see in electron micrographs do in fact represent the infective virus particles can be accepted as complete. Appropriate experiments have shown that the units carrying the infectivity are deposited by the ultracentrifuge, and are held back by filters, as if they were 100–120 mμ in diameter. They are adsorbed by, and eluted from, red cells just as the visible particles are (figure 2). What is still uncertain is whether all the particles which can be seen are 'complete', in the sense of being able to enter a susceptible cell and induce infection, giving rise to like units capable of indefinitely carrying on the chain of infection and multiplication. It is well known that if virus is not produced under carefully controlled optimal conditions many of the particles are in fact not infective in this sense. With optimally prepared virus, current estimates suggest that only between a half and a tenth of the particles present can initiate continuing infection.

One may summarize the morphological findings by saying that the visible particles show a rather wide range in size and shape, but that we are clearly concerned with a relatively homogeneous population of biological units and not, for example, with a more or less random accumulation of cytoplasmic fragments from damaged and disintegrating cells.

CHEMICAL COMPOSITION OF INFLUENZA VIRUS

It is not particularly difficult to prepare a few milligrams of influenza virus by standard techniques, but it is far from easy to satisfy one's critics that any given preparation contains no significant proportion of material other than influenza virus particles. All the available data on the composition of influenza virus are based on the assumption that the appropriate technique—which usually involves adsorption on, and elution from, red cells, followed by a sequence of purifications in the ultracentrifuge—does in fact give a virtually pure suspension of influenza virus.

The composition of such virus has been studied in a number of laboratories, with results that are broadly consistent except with regard to the vital matter of nucleic acid content. There is sufficient variation in the results, however, to suggest that none of the analyses are accurate to more than one significant figure. Nor, despite the figures given in the literature, does one yet feel justified in accepting claims that there are significant differences in the composition of different strains of influenza virus. With these reservations, one may tabulate the observations on the chemical composition of purified influenza virus. Physical measurements suggest a water content of around 40 per cent, and this must be remembered in any consideration of the chemical findings, which are expressed in terms of the percentage composition of thoroughly dried material.

Chemical constitution of dried influenza virus

	per cent
Elementary analysis:	
Carbon	52
Nitrogen	9·5
Phosphorus	0·9
Lipids (23 per cent):	
Phospholipid	11
Cholesterol	5
Neutral fat	7
Protein	65
Carbohydrate	10
Nucleic acid (ribonucleic acid)	0·8

Some of these figures call for comment. The carbohydrate value is much higher than would be accounted for by the ribose of the nucleic acid, and according to Knight [5] mannose, galactose, and hexosamine are present. These are precisely the components that are present in all the mucoproteins with which influenza virus reacts enzymically, and there is necessarily a rather strong suspicion that the carbohydrate has been derived directly from the host cell and may not be an intrinsic part of the virus particle.

The lipids present are also of the same general character as those to be found on the surface of the cell of any vertebrate. The given total of 23 per cent is from Taylor, Sharp, *et al.*, and higher

FIGURE 1 – *Electron micrograph of purified influenza virus, showing the moderate degree of variation in size and shape.* (× 20,000)

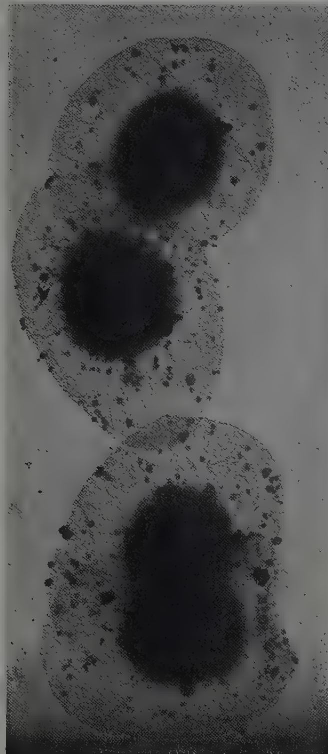

FIGURE 2 – *'Ghosts' of fowl red cells on which particles of Newcastle disease virus (closely related to influenza virus) have been adsorbed.* (× 3,200)

Electron micrographs by R. F. Mitchell and G. L. Ada, previously unpublished.

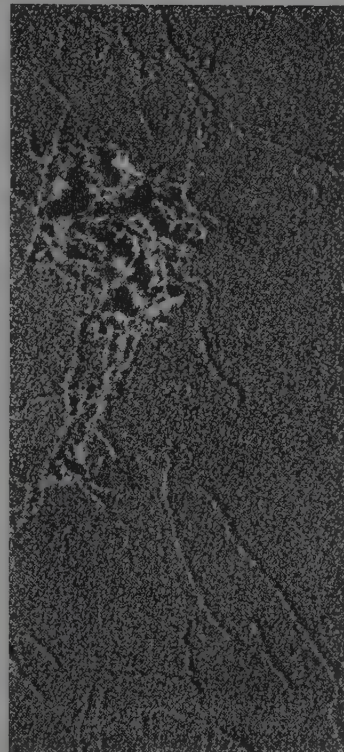

FIGURE 3 – *A receptor substance—macromolecules of the urinary mucoprotein which can serve as receptor substance and as substrate for the influenza virus enzyme.* (× 30,000)

values have been obtained by others. It is interesting in this connection to note Cohn's [6] finding, reached by adding labelled phosphorus to chick embryos, that the chief effect of infection by influenza virus is to increase greatly the uptake of phosphorus into the phospholipid fraction.

Analyses of amino acids from influenza virus protein have been published, but, as would be expected, they show the same type of distribution as is found in cell extracts. The most important finding in relation to the protein is that a significant proportion (20–30 per cent of that present on the virus surface) reacts immunologically with sera prepared by immunizing rabbits with the corresponding host-cell extract. Purified egg virus reacts with an anti-embryo extract serum; purified mouse virus with an anti-mouse serum. It has never been clearly established, and perhaps never will be, whether this activity is due to contamination with host protein or whether it is due to protein actually incorporated in the virus particle.

The nucleic acid content of the particles is a matter of controversy, primarily because of the very considerable technical difficulty of estimating small amounts of nucleic acids in complex material containing sugars and phosphorus-containing substances other than nucleic acid. By combining three different approaches—relating respectively to the nature of the sugar in extracted nucleic acid, phosphorus estimations after exhaustive lipid extraction, and ultra-violet absorption curves—Ada, in Melbourne, has concluded that the amount of DNA present is far less than one molecule per virus particle, and that the total nucleic acid is considerably less than that claimed by previous workers. His estimate is 0·8 per cent of RNA.

If we now look over the physical and chemical characters of influenza virus as outlined above it becomes very difficult to quarrel with Bauer's phrase that the influenza virus is 'merely a fragment of diseased cytoplasm.' Virtually the only

quality that distinguishes it at the physico-chemical level is the morphology of the particles. If they are to be looked at as fragments of host-cell cytoplasm, then we must admit that they are fragments of material within which a new and significant structural reorganization has occurred.

Relatively little work on the development of morphological units in the infected cell has been reported. The two groups of American workers who have studied thin sections of embryonic cells by electron microscopy agree that no internal structures can be seen in the early stages of infection, the only abnormality being the accumulation of spheres and filaments along the free edge of the cell. In their view, influenza virus particles are either 'created' by the extrusion of suitably organized portions of the cell's surface, or the process of intracytoplasmic development of new virus particles produces no visible disorganization of the cytoplasm. With the related, but more highly pathogenic, viruses of Newcastle disease and fowl plague there is visible damage to cytoplasm and mitochondria in unsectioned tissue-culture cells. Flewett and Challice observed long filaments in the cytoplasm, from which fowl plague virus particles appeared to develop by fragmentation. Because of the method used, however, it is not certain that the filaments observed were actually in the cytoplasm and not already on the surface.

THE DEVELOPMENT OF INFLUENZA VIRUS IN THE HOST CELL

Many points about the intracellular multiplication of influenza virus are still obscure, and it is possible that the current picture may need fairly radical alteration if some of our assumptions about the quantitative relationship between haemagglutinin and infectivity titres and numbers of virus particles should be found to be erroneous. However, at the present time there seems to be good evidence for the following sketch of what happens when a virus particle enters and initiates infection in a susceptible cell of the allantoic cavity.

The first step is the adsorption of virus by some of the mucoprotein 'receptors' of the cell surface (figure 3). Once attached, it is probably folded into the cytoplasm by a process analogous to the wetting of a dust particle by a drop of water. In the cytoplasm an interaction between virus and some part of its environment initiates a process by which the virus particle disappears as a demonstrable entity. Using a little imagination, and some hints from the behaviour of the bacterial viruses, we can picture an unfolding of the particle, allowing its genetic elements to make effective contact with the cell components that will guide in the energy and substance needed for their replication. No virus is detectable for three to four hours after entry, and during this period we must postulate a process of rapid multiplication of genetic elements. Their replication is probably for the most part as independent 'linkage groups', although the genetic evidence points also to the possibility of independent replication of smaller genetic blocks or units. The elucidation of the relationship between genetic replication and the reproduction of what may be called the somatic qualities of haemagglutinin and antigen is a major problem for the future. It has been suggested that the complex of genetic units with protein-synthesizing elements of the host cell containing RNA could well be equated with the 'soluble complement-fixing antigen' which is produced in relatively large amount in infected cells. This, however, may represent a 'confusion of categories' and is probably unacceptable to most virologists. Whatever the process, after about four hours new infective and haemagglutinating particles are demonstrable within the cells, and a little later they begin to be released into the environment. The process of liberation does not resemble the explosive release of virus from an infected bacterium. It is a process which reaches its peak two or three hours after the first appearance of virus and may continue for perhaps as long as twenty-four hours (a total of about 100–200 descendant virus particles per cell being released). Gross damage to the cell does not become apparent until some hours after the period of most active production and liberation of virus. Under a variety of mildly disadvantageous conditions the new brood of virus contains a proportion (sometimes more than 99 per cent) of 'incomplete' virus, which can agglutinate red cells but cannot induce typical infection of fresh susceptible cells.

CONCLUSION

This outline of the properties and behaviour of one of the simplest of all living organisms must necessarily be very incomplete, but even within the framework of what we know already it seems to present an important lesson for general biology. That lesson is the significance of pattern. Considered apart from the specific patterns carried by the macromolecules concerned, any type of influenza virus particle is like any other, and distinguishable from a fragment of host-cell cytoplasm only by a moderate regularity of size and

shape. Some of the proteins, however, have new specific patterns replacing—or perhaps additional to—the patterns characteristic of host proteins, and we can feel certain that the vital 0·8 per cent of RNA carries a code that differs sharply from that of the cytoplasmic RNA from which it must be derived. The possibility that the large amount of lipid in the particle also has its own series of specific patterns is something that must await the emergence of the appropriate technical approach. On this view, then, the influenza virus is no more than a fragment of living matter carrying patterns—patterns which determine whether the particle is, like most laboratory strains, virulent only for the chick embryo or, at the other extreme, capable of initiating a deadly pandemic like that of 1918.

In the last analysis, molecular pattern is a strictly chemical concept, and in the case of antigenic specificity the actual groups responsible for determining antigenic pattern have been defined in a number of artificial antigens. Landsteiner and Pauling are the two names that come first to mind in connection with this development. The enzymologists have been much less successful. Most of the enzymes liberated for specific functions have now been purified and crystallized. Much has been learnt of the specificity of enzymic action in terms of the chemical structures which can or cannot be split, and do or do not act as competitive inhibitors of enzymes. Yet, just as we have no alternative to speaking of the specific aspect of antibody as the 'complementary aspect' of the known or unknown determinant of the corresponding antigen, so we are equally compelled to speak of the essential enzyme structure as a (perhaps slightly distorted) chemical pattern, complementary to the specific substrate grouping. Where we have to deal with natural antigens—as in pathogenic micro-organisms—or with the all-important sequences of enzymic action within the cell, we are reduced simply to making the best use we can of purely functional concepts.

We have a clear indication that single genes may, or perhaps must, be specifically related to functional protein patterns expressible as antigen or enzyme. The great bulk of genetic work on organisms more complex than bacteria and moulds is, however, concerned with the systematization of the inheritance of morphological and functional characters, which are quite beyond any chemical definition. The characteristic type of generalization is the chromosome map, a pattern that may, in the last analysis, represent another pattern in the arrangement of purines and pyrimidines in a macromolecular chain of DNA, but which is most unlikely ever to be so transcribed. With all respect to the triumphs of the biochemical approach, it is becoming more and more evident that the understanding of the basic processes of biology may need an entirely different approach, based on sequences of significant patterns.

It may be that the next development of 'communications theory' will be in the heart of the cell, where 'information' seems to flow steadily from the genes to the functional and productive divisions of the cell, through chains of patterned macromolecules; no doubt the inevitable 'feedback' controls are similarly mediated. In many ways the most effective way of picturing the activity of the influenza viruses, and perhaps of many other viruses, is to think of them as a set of punch-cards maliciously inserted into vital parts of a fantastically complicated computing machine. An essential part of the machine's activity is to produce, also in the form of punch-cards, new programmes for its own functioning. Something analogous to virus action would result when the machine found itself compelled to produce programmes that would lead inevitably to its malfunction or destruction.

A completely adequate justification for research on influenza virus is to be found in its importance as a cause of human disease. Yet at the present time there is perhaps more significance attaching to the quest for an understanding of the nature of its attack on the susceptible cell. To the biologist an animal virus is pre-eminently a probe for exploring the structure and functioning of the vertebrate cell, and with the growing development of ideas of specific pattern it becomes of special importance. It may not be wholly a fantasy to say that in influenza virus we have a tool—a uniquely suitable tool—with which to break some of the codes that lie at the basis of cellular life.

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The first English microscopist: Robert Hooke (1635–1703)

CHARLES SINGER

Hooke's genius for mechanical experiments is widely known, but his brilliant biological work is much less appreciated, perhaps because almost all of it was done within the brief space of two years. His *Micrographia* of 1665, a number of illustrations from which are figured here, was not only an outstanding work in itself but of very great value in stimulating the work of his contemporaries—notably Grew, Malpighi, Swammerdam, and Leeuwenhoek.

The earliest observations with the aid of the compound microscope, invented by Galileo, were made by his fellow members of the 'Academy of the Lynx,' and notably by its president Federigo Cesi (1585–1630) and its secretary, Francesco Stelluti (1577–1653), between 1611 and 1624 [*Endeavour*, **12**, 197, 1953]. During the next few years these records were somewhat amplified, but they excited very little scientific interest. From 1625 to 1665 is an almost blank period in the history of micrography. Except for certain observations on the capillary blood vessels, made by Malpighi about 1661, nothing very significant appeared until the publication by Robert Hooke (1635–1703) of his great *Micrographia* (London, 1665). Production of this was stimulated by the newly founded Royal Society in England, somewhat as Stelluti and Cesi's *Apiarium* was elicited by the short-lived *Accademia dei Lincei* in Italy. Unlike the *Apiarium*, however, Hooke's *Micrographia* attracted wide attention, was much read, and became at once a classic of the 'New Philosophy' which we now call 'Science'.

There is general appreciation of the mechanical skill, inventive genius, and extraordinary scientific insight of Robert Hooke. These qualities of his need no discussion here, for they have been considered by E. N. da C. Andrade. Hooke's other talents have, however, been less noticed, and here we consider his exceptional capacity as an observing naturalist.

Galileo and his successors had riveted men's attention on the vastness of the universe, as the telescope revealed star beyond star, and the times were full of wonder at such things. But in 1665 men had had no experience of the world of complex living things of extreme smallness which Hooke was the first to explore in any detail. As to structures so small as to be beyond the reach of vision, there had hitherto been nothing but speculation. Hooke's *Micrographia* of 1665 was a messenger from the newly revealed minute world, as Galileo's *Sidereus Nuntius* of 1610 had been a messenger from the newly revealed heavens. Hooke says of his instrument that 'the power of considering, comparing, altering, assisting, and improving' the works of nature can be 'so far advanced by the helps of Arts and Experience, as to make some men excel others in their Observations and Deductions, almost as much as they do the Beasts.' He was perforce primarily a physical experimenter, and to biological observation he gave little more than two hurried years, 1663 and 1664. His truly extraordinary discoveries made in that short time are set out in this book, especially in its beautiful figures. A few of its figures were, perhaps, drawn by his friend, Christopher Wren (1632–1723), who, we may note, was the exact contemporary of the most industrious of all the great microscopists, Antoni van Leeuwenhoek (1632–1723).

Of Hooke's positive biological contributions the best known is his introduction of the word 'cell'. In a thin section of a piece of cork he observed a series of 'pores'. 'I told several lines of these pores, and found that there were usually about threescore of these small Cells placed end-ways in the eighteenth part of an Inch' (figure 2). He could, of course, have had no idea of the nature of a 'cell' in the modern sense, and he uses that word as equivalent to the walls of a small chamber. Nevertheless, one of his figures displays the outlines of living cells on the surface of a nettle leaf (figure 4), and he gives a good account of the stinging apparatus. In a moss also he describes and figures the cell outlines in the leaves and stem (figure 5D).

'Moss has a root with small strings or suckers out of which springs the body, which is fluted with small creases which run parallel to the whole stem; on the sides of this are thick set a multitude

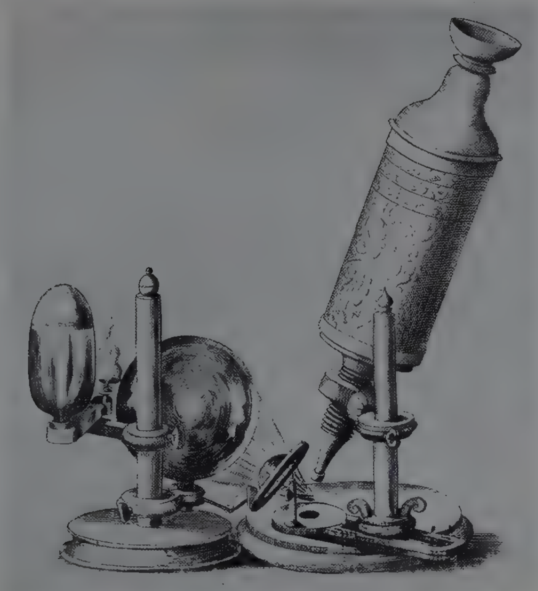

FIGURE 1 – *Hooke's microscope. Alone among the classical microscopists, he habitually used the compound instrument. The cylindrical tube, 6 or 7 inches long, could be lengthened by four draw-tubes. The eye-lens was plano-convex and rested on the top of the cylinder. The objective was double convex, of very short focal length, and had a pinhole diaphragm. For certain purposes he introduced a third glass between the two. The cup-like structure above the cylinder merely kept the eye at the correct distance from the eye-lens. The picturesque illuminating apparatus can hardly have been very efficient. (All illustrations, except figure 10, are from Hooke's* Micrographia, *London, 1665.)*

FIGURE 2 – *Cell walls in a thin section of cork.*

FIGURE 3 – *Surface of a rose-leaf infected with a mould of the Ascomycetes type. Stages in the emergence of the asci are well seen.*

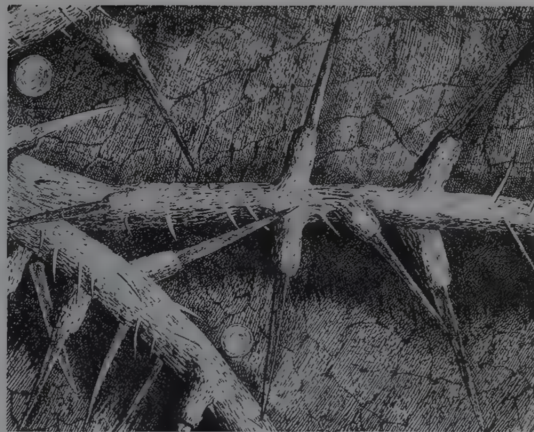

FIGURE 4 – *Part of the underside of a stinging-nettle leaf. Small simple bristles are distinguished from the larger stinging-hairs with bulb-like cellular bases. Outlines of the epidermal cells are seen and nuclei of some are perhaps vaguely indicated.*

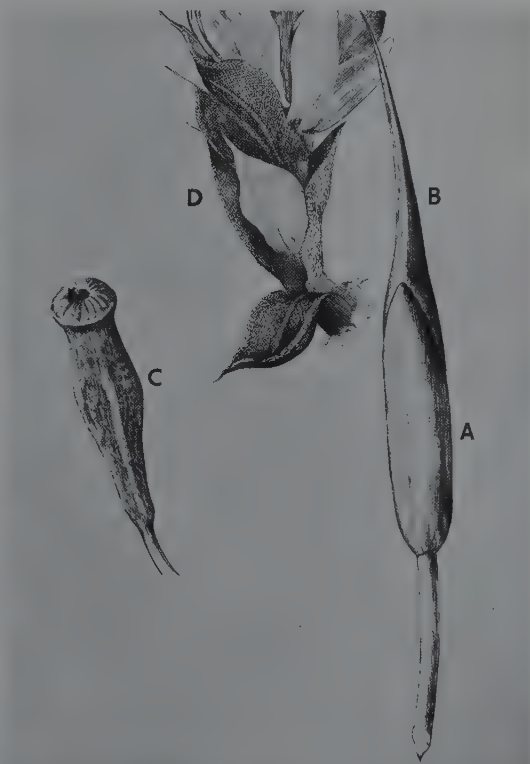

FIGURE 5 – *Moss-plant (possibly* Polytrichum*). On the surface of some leaves the cells' outlines are well seen.* (B) *Seta, bearing capsule with calyptra in place.* (C) *The calyptra has been shed and the operculum is displayed.*

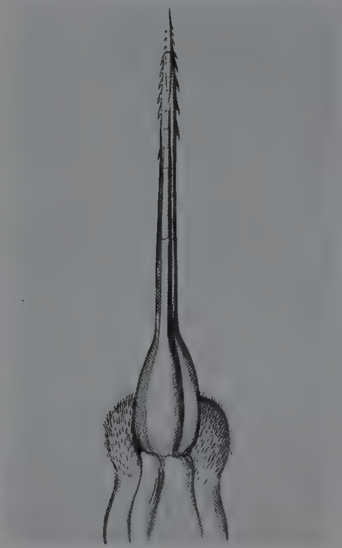

FIGURE 6 – *Bee's sting with poison-bulb at base. The director and the two barbed piercers are recognizable.*

FIGURE 7 – '*Tarsus*' *of house-fly expressing well the hairs on the last three joints, the terminal claws, and the two pads with their minute hairs.*

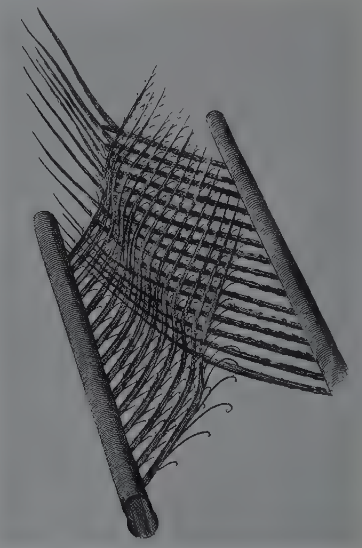

FIGURE 8 – *Elements of a goose's feather, showing minute hooks on one barbule interlocking with knobs on the other.*

of fair, well-shap'd leaves all the surface of each side of which is curiously cover'd with a multitude of little oblong transparent bodies. [These cells are shown clearly in figure 5D.] From the top of the leaves there shoots a small transparent hair or thorn [figure 5A], on which grows a large seed case [capsule], covered with a thin skin [calyptra], terminated in a long thorny top [figure 5B], which, by degrees, cleaves and at length falls off and leaves the seed case to ripen. This before the seed is ripe, appears like a flat barr'd button [operculum]. As it ripens the button grows bigger, and a hole appears in the middle of it [figure 5C].'[1]

Very striking are his observations on moulds. One kind (doubtless a *Mucor*) he describes as growing on the old damp leather of books. Another kind, one of the Ascomycetes, he saw arising on the underside of rose-leaves in autumn. Of this latter he figures the development of the spore-bearing filaments (figure 3).

Among Hooke's figures taken from the animal kingdom is one showing the structure of the bee's sting, which is better drawn than described (figure 6), and one of the foot of the fly, superbly represented (figure 7). Both of these were to become classical objects of microscopical study. His representation of the structure of a feather (figure 8) was not improved upon until the later part of the nineteenth century. His most conspicuous figures are those in the enormous plates of the louse and the flea. The latter is some 16 inches long (figure 9) and evidently suggested the curious drawing 'The Ghost of a Flea' by the artist William Blake (1759–1829) 150 years later (figure 10).

The acuteness of Hooke as an observer is peculiarly well illustrated by his treatment of the compound eyes of insects. These organs consist of aggregates of large, and often immense, numbers of elements, every one of which is provided with its own lens and nervous apparatus. Each element is capable of yielding a picture of an object from an angle slightly different from that of its neighbours. How all these pictures can be fused into one—if indeed they are fused—and how the insect can react to the result, is a current problem of animal psychology. Hooke's genius is marked by the rapidity and assurance with which he instantly seizes on such problems.

'I took a grey Drone-Fly [here a dragon-fly] that had a large head and, cutting it off, I fixed it with the forepart or face upwards upon my Object Plate [figure 11]. I found this Fly to have the biggest clusters of eyes in proportion to his head of

[1] For the sake of clarity and conciseness this passage from the *Micrographia* and those which follow have been abbreviated and the spelling and punctuation slightly modernized. They should not therefore be taken as verbatim.

any small kind of Fly that I have yet seen. The greatest part of the head was nothing else but two large and protuberant bunches. The surface of each of these was shaped into a multitude of small Hemispheres, ranged over the whole surface in very lovely rows. I was assured of this by the regularly reflected Image of Objects which I moved to and fro between the head and the light, and by examining the Cornea or outward skin after I had stript it off, and by looking both upon the inside and against the light. Every one of these Hemispheres reflects as exact and perfect an Image of any Object from the surface as a small Ball of Quick-Silver of that bigness would do. In each of these Hemispheres, I have been able to discover a Landscape of those things which lay before my window, as I could also the parts of my window [figure 14], and my hand and fingers, if I held it between Window and Object.'

One of Hooke's best connected pieces of biological observation is on a common gnat (figure 12). During its life this creature goes through certain complete changes, or metamorphoses, which are now made familiar to most schoolchildren in the course of their nature study. These stages Hooke was the first to picture exactly.

''Tis a creature [the aquatic larva of a Culicine gnat], that wholly differs in shape from any I ever observed; nor is its motion less strange. It has a large head in proportion to its body [figure 13]. It has two horns, almost like the horns of an Oxe inverted, and with tufts of bristles at the top. These horns could move easily, this or that way, and might, perchance, be nostrils. [They are, in fact, the antennae, by the incessant movement of which the animal feeds on minute organisms in the water.] It has a pretty large mouth, which seem'd much like those of Crabs and Lobsters [i.e. with laterally movable jaws] by which I have often observ'd them to feed.

'I could perceive, through the transparent shell, several motions in the head, thorax, and belly, very distinctly, of differing kinds which shew of how great benefit the use of a *Microscope* may be for discovery of Nature's course in Animal bodies. By it we have the opportunity of observing her

FIGURE 9 (*left*) – *Head and thorax of flea.* (*Original size as drawn by Hooke, but reversed for comparison with figure* 10.)

FIGURE 10 (*right*) – *'Ghost of a Flea,' from a drawing by the artist William Blake* (1757–1827). *It is clearly influenced by Hooke's drawing. The first joint of the forelimb is the lower jaw of the ghost. The pro-, meso-, and meta-thorax of the animal are the plaques on the neck of the ghost. The bristles on the pro-thorax of the animal are the curious strands of hair of the ghost. Other resemblances will be easily traced.* (*Reproduced by courtesy of the Trustees of the Tate Gallery, London.*)

FIGURE 11 – *Head of the 'grey Drone-fly', i.e. a dragon-fly, an unidentified species. Hooke estimated* 14 000 *'hemispheres' in it.*

FIGURE 12 – *Adult female gnat* (*possibly* Stegomya).

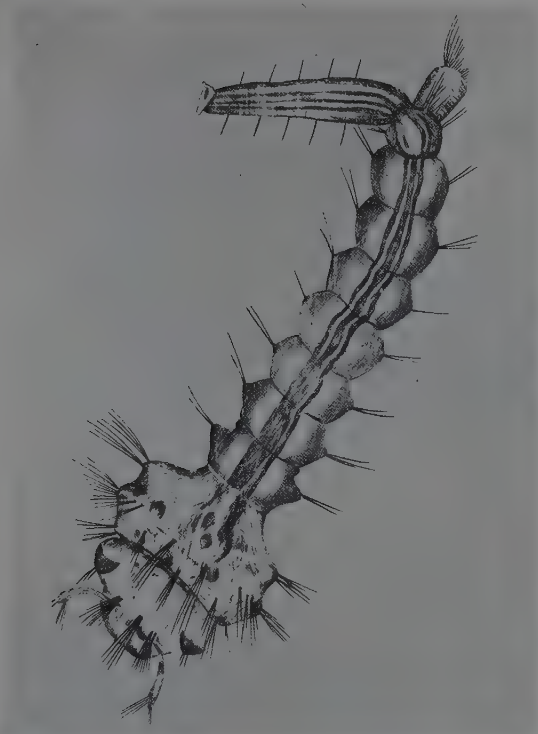

FIGURE 13 – *Larva of gnat.*

FIGURE 15 – *Pupa of gnat. Hooke has indicated by dotted lines the position of the abdomen when the animal sinks.*

through these pellucid teguments of Insects, acting according to her usual course and way, undisturbed, whereas, when we endeavour to pry into her secrets by breaking open the doors upon her, and dissecting and mangling creatures whil'st there is life yet within them, we find her indeed at work, but put into such disorder by the violence offer'd. How differing a thing we should find, if we could, as we can with a *Microscope*, quietly peep in at the windows, without frighting her out of her usual byas.

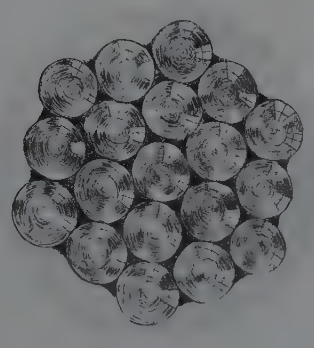

FIGURE 14 – *Part of the surface of the eye of a house-fly stripped off. It contains* 19 '*hemispheres*'. *In each is seen the reflection of the two windows of Hooke's workroom.*

'The form of the whole creature may be plainly enough perceiv'd by the *Scheme* [figure 13], the hinder part or belly consisting of eight jointed parts, from the midst of each of which, on either side, issued three or four small bristles or hairs. The tail was divided into two parts of very differing make; one having many tufts of bristles, which seem'd to serve both for the finns and tail, for the Oars and Rudder, of this little creature, wherewith it was able, by frisking and bending its body nimbly to and fro, to move himself any whither, and to skull and steer himself as he pleas'd. The other seem'd to be the ninth division of his belly, and had many single bristles on either side. [This is the respiratory siphon, the end of which when at rest is at the surface.] From the end of it, through the whole belly, there was a kind of Gut of a darker colour. The *Thorax* or chest, was thick and short, and pretty transparent, for through it I could see the heart to beat, and several other kind of motions. It was adorn'd up and down with several

tufts of bristles. The head was likewise bestuck with several of those tufts. It was broad and short, had two black eyes and two small horns.

'Both its motion and rest is very strange and pleasant. Where it ceases from moving its body, the tail, lighter than the rest and a little lighter than the water it swims in, presently buoys it up to the top of the water, where it hangs suspended with the head downward like our Antipodes. If they do, by a frisk, get below that superficies, they presently ascend again unto it. The hanging of these in this posture, put me in mind of a certain creature I have seen in London, brought out of America, which would suspend itself by the tail, head downwards, and was said to sleep in that posture, with the young in a Purse, provided by Nature for the production, nutrition and preservation of her young ones.' [This was an opossum, a marsupial creature then on show in London, but not described scientifically until 1698.]

Hooke now relates the change of the larva into the still aquatic pupa, and the emergence from the pupa of the perfect winged insect.

'But that which was most observable in this [insect] was its Metamorphosis or change. This made me more diligently to watch if I could find them at the time of their transformation. Not long after, I observ'd several changed into an unusual shape, wholly differing from that they were of before, their head and body being grown much bigger and deeper and their belly, or hinder part smaller, and coyl'd about this great body. [They are now pupae (figure 15)]. The head and [respiratory] horns now swam uppermost, and the whole body seem'd much lighter; for when by my frighting of it, it would, by striking out of its tail, sink towards the bottom, the body would more swiftly re-ascend than when it was in its former shape.

'I still marked its progress and found it to grow bigger and bigger, Nature accoutring it for the lighter Element, of which it was now going to be an inhabitant; for, by observing one of these with my Microscope, I found the eyes to be altogether differing from what they seem'd before, appearing now all over knobbs, like the eyes of Gnats. At length, I saw part of this creature to swim above, and part beneath the surface, below which it would quickly plunge, if I by any means frighted it, and presently re-ascend. After a little I found that the head and body of a Gnat began to appear and stand clear above the surface. By degrees it drew out its leggs, first the two formost, then the others, at length its whole body, perfect and entire, out of the hulk (which it left in the water), standing on its leggs upon the top of the water. By degrees it began to move, and after flew about the Glass a perfect Gnat [figure 12].'

The appearance of *Micrographia* was the signal for a burst of microscopic research. In Italy Marcello Malpighi (1628–84) had already begun his microscopic explorations, and now he became more active. In England Nehemiah Grew (1641–1712) took up Hooke's investigations on plants, and his figures became standard for a century and a half. In Holland two micrographic geniuses, Jan Swammerdam (1637–80) and Antoni van Leeuwenhoek (1632–1723), immensely extended knowledge of the microscopic world. None of these had Hooke's imaginative insight or literary skill, and, what is specially remarkable, none of the five classical microscopists was in intimate scientific contact with the others or had significant pupils. After them follows again a relatively barren period, seldom broken until the optical properties of the microscope were improved in the nineteenth century.

Considering his numerous other occupations, the pioneer character of his observations, and that he gave but two years to biological work, the achievement of Hooke is perhaps the most noteworthy of that of all the classical microscopists. Not the least of his excellences is that his discoveries were set forth in a clear and attractive fashion which still gives pleasure as literature. Hooke was not only one of the most skilled and ingenious technicians that this country has produced, not only a scientific theorist of a high order, but a first-class observing naturalist and a master of the English language. Such a variety of talents has very seldom been assembled in one person.

The magnification used by Hooke nowhere exceeded 150 diameters, and varies from figure to figure. Moreover, some of his originals have been somewhat reduced to fit our pages, so that it is difficult to state an exact degree of magnification for each figure. As examples, however, it may be mentioned that in *Micrographia* the magnification of the feather (figure 8) is about 124 diameters, of the flea (figure 9) about 120 diameters, and of the Ascomycetes (figure 3) about 56 diameters. We are indebted to Miss Margaret E. Rowbottom, of the Wellcome Historical Medical Museum, for these estimates.

The twelve whites

E. N. WILLMER

The sensation that we call white—necessarily subjective and difficult to define precisely—can be produced by irradiating the eye with a mixture of all visible wave-lengths in proportions corresponding to, for example, that of the light of the north sky. There are, however, many other circumstances in which the sensation of white can arise. Moreover—a point of importance in considering the mode of action of the receptors of the retina—both eyes can simultaneously register the sensation of white while exposed to different stimuli.

Any satisfactory theory of colour vision must integrate the physical properties of light, the physiological properties of the retina and its connections with the appropriate regions of the brain, and the psychological properties of mind. In so doing, the theory must account adequately not only for the sensations of colour but for the more basic, and perhaps less spectacular, sensation of white, for this too must have its origins on the physical, physiological, and psychological planes. Moreover, white is in some ways different from colour in that the sensation of it can arise under a wide variety of conditions. The sensation of white, of colourlessness, or simply of 'light', is probably the most primitive visual sensation, and the sensations of colour almost certainly demand accessory mechanisms of one sort or another.

Any precise definition of white is almost impossible. Whiteness, like colour, is strictly subjective, synonymous with the complete absence of any sensation of hue, and like colour it depends as much on the physiological mechanisms as it does on the physical characteristics of the light. It is true that, other things being equal, the light of the cloudy north sky at noon, when reflected from a magnesium oxide surface, may be called white. A black body radiating at a colour temperature of about 5500° K may also evoke a sensation of white. Either could be arbitrarily adopted as a standard, but nevertheless both would evoke a sensation not of white but of green if the eye of the observer had been previously exposed to a bright red light for some minutes and had become 'adapted' to it. Figure 4 illustrates that a white page may in some circumstances appear to be anything but white.

Sunlight may sometimes be taken as white, but generally it appears yellowish. Under some conditions it can certainly appear white, and it is a curious phenomenon, having in all probability both a physiological and a psychological basis, that the whitest, or least saturated, surface in the field of view at any one time tends to be regarded as white until something whiter is introduced. Furthermore, surfaces known to be basically white, e.g. white paper or a white wall, are generally still called white, even when predominantly red (or indeed any other coloured light) is being reflected from them.

The various conditions under which the sensation of white can arise are, briefly, as follows.

1. Under ordinary daylight or 'photopic' conditions (i.e. when the eye is light-adapted and when colours, if present, could be fully distinguished) the sensation of white is normally produced when the eye is simultaneously irradiated with light of all wave-lengths of the visible spectrum, in amounts roughly corresponding to their distribution in the spectrum of north daylight or of a black body radiating at 5500° K. Almost any arbitrary standard could be chosen as white under conditions approximating to those described, since, under reasonably normal conditions, it could be made to evoke a colourless sensation. As mentioned above, the eye tends to adapt itself and to desaturate colours which are nearly white until one of them is regarded as being white.

White can therefore result from irradiating the eye with an appropriate mixture of all wave-lengths of the visible spectrum at once.

2. A sensation of white also results from mixing, in the correct proportions, certain pairs of lights of particular wave-lengths, the so-called complementary pairs. For example, a yellow light when mixed with the right amount of blue becomes a white (figure 1); similarly the addition of red light to the appropriate blue-green also causes the disappearance of all colour, and such mixtures of pairs of wave-lengths can be perfectly matched with whites produced by the whole spectrum as already described. It should perhaps be emphasized that mixture of blue and yellow pigments

FIGURE 1 – *The white on the left is a mixture of blue with monochromatic yellow. The white on the right is a mixture of blue with yellow made by mixing red and green.*

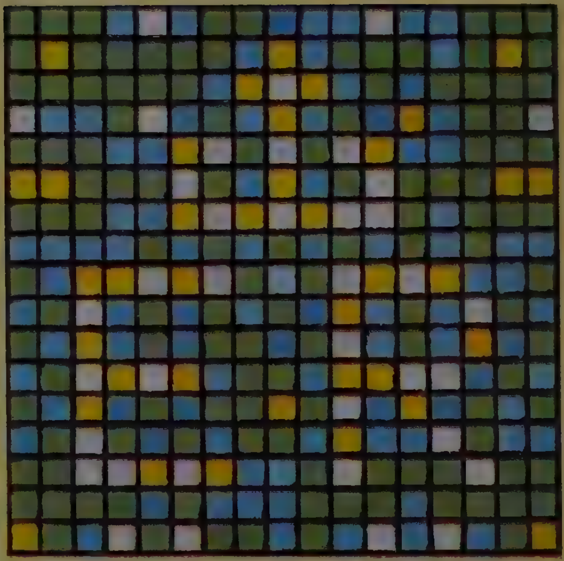

FIGURE 2 – *If you cannot see a pattern on this figure, examine it from a distance of more than 4 metres.* (*This figure should be examined in daylight.*)

FIGURE 3 (*right*) – *Fixate the green spot from a distan of 3 or 4 metres, and observe what happens to the yello and white spots. Compare them in colour with the white rin*

FIGURE 7 – *Hold the page very close to the face in such a position that the right eye looks directly at the white spot. Bring the right-hand page slowly forward from a position behind the field of view of the right eye until the coloured patches slowly*

FIGURE 4 – *Fixate the white point marked between the red and green fields for 20 seconds or more. Rapidly transfer the gaze to the black spot in the lower half of the diagram and observe the 'white' fields.*

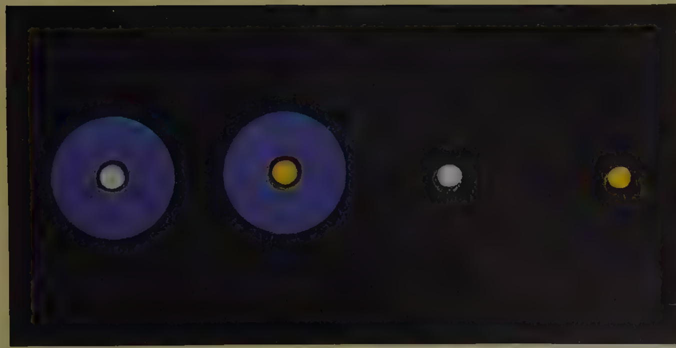

FIGURE 5 – *Examine these spots from a distance of about 4 metres. Fixate each in turn, avoiding eye movements, and arrange in order of 'whiteness.'*

FIGURE 6 – *From a distance of 4 metres fixate in turn the crosses in the centres of the two circular fields with one eye; avoid eye movements. The results demonstrate the effects of foveal tritanopia. (This figure is best examined in daylight.)*

enter the field of view. Keeping the eye directed at the white spot, note the colour of the patches when they first appear. Repeat with the left-hand page, using the left eye. Particularly note the appearance of the upper patch on the left-hand page.

does not lead to the same result, since the effect of such a mixture is subtractive while that of lights is additive.

White can therefore result from the mixture of two or more isolated wave-bands, and the whole spectrum is not necessary.

3. It is a common experience that in the hours of twilight blue flowers apparently lose their colour and become white, while red flowers appear black. An observer in a dark room, examining a visual field illuminated by blue or blue-green light and gradually reducing the intensity of the light, notices that at a certain stage, depending on the wave-length, the light becomes colourless. Indeed, below a certain level of luminance (brightness) any light, with the possible exception of the far red—it does not matter whether it is monochromatic or covers the whole spectrum—will thus lose all colour. Moreover, if a light which appears white to the observer under photopic conditions is gradually reduced in luminance until it is only just visible with the fully dark-adapted eye (i.e. under 'scotopic' conditions), the sensation which it evokes remains colourless, in the absence of disturbing factors, until it fades away through grey to black. There is thus a smooth transition from photopic white to scotopic white, even though the one may be produced by the whole spectrum and the other by a single limited wave-band.

White can therefore result from light of any or every wave-band (except possibly extreme red), provided that the intensity is below a certain level and that the observer is dark-adapted.

4. All colours, when made sufficiently bright, tend to lose their colour; they desaturate, and eventually appear white. This naturally happens most easily with the originally less saturated yellows and greens, and least easily with the highly saturated violet and red. Colours thus not only desaturate into grey or black at the lower levels of luminance, but they desaturate towards white at high luminances: this is not necessarily the result of a wider spectral band reaching the eye at high luminances, though this may sometimes contribute.

White may thus result from the desaturation of colours at high luminance.

5. The pattern on figure 2, when seen at close quarters, is probably meaningless to most people, but when viewed from a distance (3–4 metres) its significance is apparent. Similarly, the yellow spot which is surrounded by blue in figure 5 will, when viewed from about 4 metres, appear to be completely colourless. If firmly fixated, it may appear to be even whiter than the genuinely white spot on a black ground when that is similarly fixated. In fact, when each is examined in turn, the spots in this figure can be arranged in order of increasing whiteness to the left. The cause of these anomalies is uncertain. They may result partly from simultaneous contrast; they may be caused by the spreading and overlapping of images on the retina; or they may be of the same nature as the effects described in the next section.

White thus results when a small yellow field is surrounded by, or placed next to, a small blue field.

6. Study of the effects of steady fixation on the appearance of colours has shown that the central fovea (the point of most distinct form-vision in the eye) makes certain definite confusions of colour; these help to explain the appearance of the pattern which emerges from figure 2 when it is viewed from a distance, and which cause the quartered circular field of figure 6 to appear as a simple bisected field when its image falls on the fovea. A point in the yellow region of the spectrum (generally about 5700 A) can then be satisfactorily matched with white. Steady fixation of the green spot in figure 3, when the figure is viewed from a distance of 3 or 4 metres, will remove all difference of hue from the two adjacent spots, and both will appear colourless.

A sensation of white thus arises at the neutral point (approximately 5700 A) in the spectrum when vision is confined to the central fovea by means of steady direct fixation of the eye.

7. A similar phenomenon occurs with extreme peripheral vision, under photopic conditions, when a green light (about 5000 A) is flashed on the eye from a direction making an angle of more than 70° with the direction of gaze. All wave-lengths shorter than about 5000 A appear bluish under these conditions, while all longer wave-lengths appear yellowish (figure 7).

A colourless sensation is therefore aroused under photopic conditions by a narrow wave-band in the spectrum, at about 5000 A, when this illuminates the far periphery of the retina.

8. Under conditions of poor illumination the above wave-band extends along the spectrum in both directions and eventually the long wave-lengths alone seem coloured; incidentally, they now appear as red, rather than yellowish as under photopic conditions. The whole of the rest of the spectrum gives rise to a colourless sensation, and this effect, though it occurs at a higher brightness level, is probably comparable with that described previously in section 3.

Under conditions of poor illumination, though not necessarily strictly scotopic conditions, all wave-bands of the spectrum from violet to orange are seen as white by the extreme peripheral retina.

9. People with abnormal colour vision who can match all the spectral colours by means of two primaries instead of three are called dichromats. They fall into three main groups: (1) protanopes, often incorrectly called red-blind; (2) deuteranopes, often incorrectly called green-blind; and (3) tritanopes, often incorrectly called blue-blind. All such subjects have a neutral point in the spectrum which they can match with white. These neutral points occur at different points according to the defect. The average values are 4930 A for protanopes, 4970 A for deuteranopes, and 5680 A for tritanopes. The last is in the same region of the spectrum as the neutral point for the normal central fovea, and in fact the central fovea is correctly described as being tritanopic.

For dichromatic subjects there is one spectral region causing the same sensation as does the whole spectrum when combined as white, or as do any or all wave-lengths in scotopic vision.

10. When the vision of two of these groups of dichromats, the protanopes and the deuteranopes, is confined to the central fovea, as it is when such a figure as figure 6 is seen from about 3 or 4 metres away by direct and steady fixation, another effect is noted. Both circles appear to such subjects as a uniform grey, or they may appear as grey but with different degrees of brightness in the different quadrants according to the type of defect of vision present. Such subjects can, in fact, match any wave-length with white when their vision is strictly confined to the central fovea and eye movements are avoided. The sensation which they receive under such conditions is described as being identical with the white of their scotopic vision, which is presumably the same as that seen by the normal person. Tritanopes do not show this foveal monochromacy.

Protanopes and deuteranopes, in the absence of any comparison fields, see all parts of the spectrum as colourless in the central fovea and can match all wave-lengths with white.

11. When the vision of the normal person is confined to the central fovea and the eye has been previously 'adapted' to a bright red light, a large part of the spectrum, from about 5200 A (green) to the red end, becomes uniform in hue and extremely desaturated, if not actually white. Similar effects, i.e. extreme desaturation of the spectrum from the blue end to about 6400 A, follow adaptation to bright blue or blue-green. With the whole eye, very similar results are obtained if it is first adapted to violet and then to either red or blue-green. Under these conditions, large parts of the spectrum become highly desaturated, and it becomes difficult to name the hue perceived. Although superficially similar, these conditions are not identical with those described in section 4.

Adaptation of the eye to certain bright lights of restricted wave-bands is followed by a period during which large spectral regions give rise only to colourless or very desaturated sensations.

12. There are certain rare colour-blind subjects, the monochromats, who see no colour whatsoever in the spectrum; their sensation of light is, under all conditions, comparable with their scotopic sensation and may therefore be presumed to be the same as the colourless sensation, or white, of the normal person. On the basis of their relative sensitivities to the different parts of the spectrum there appear to be two, or perhaps three, classes of such subjects, and they all behave similarly.

White may thus arise under a variety of conditions. Even in the normal subject it is possible to match binocularly a normal photopic white in one eye with a scotopic white in the other, or with the white perceived when a yellow spot falls on the central fovea only, or again with an orange spot whose colour has been modified by previous adaptation to violet and red. It is pertinent, therefore, to inquire what the various photoreceptor cells are doing under all these varied conditions. Clearly, they cannot always be doing the same thing, and this is a thought which, if extended, might be found to be somewhat disturbing to the commonly accepted view that if two visual fields match, then the corresponding receptors in the retina are being equally stimulated by the two fields. In the case of white they certainly need not be. When figure 3 is examined by direct fixation of the central green spot from a distance of about 3 or 4 metres the white ring will be seen to surround two white spots. These two spots are falling on the dichromatic foveal centre, while the ring falls on the trichromatic periphery. Moreover, if the illumination is reduced there will come a time when, however they are observed, all the spots appear white or grey and only monochromatic ('twilight') vision is being used. The sensation of white can thus arise as the result of appropriate stimulation of monochromatic, dichromatic, or trichromatic mechanisms, and in the perception of white the eye does not appreciate the change-over from one system to another.

Storms in the ionosphere

SIR EDWARD APPLETON

For more than a quarter of a century the terrestrial ionosphere has been regularly explored by vertical radio-sounding. In addition to the regular features in its behaviour which have been thus revealed, world-wide disturbances in its upper structure have been observed to occur at times of magnetic storms. Such ionospheric storms are responsible for many of the interruptions which occur in short-wave communications over global distances.

The ionosphere is a shell of ionized air surrounding the earth at high atmospheric levels. Its exploration and theoretical study have a practical as well as a scientific importance, for we know that it is due to the reflective power of the ionosphere that short radio waves can be successfully transmitted over great distances. Moreover, the ionosphere itself constitutes a laboratory in which the radiophysicist can study the atomic processes of ionization and electronic recombination under low-pressure conditions not realizable at ground level. The ionosphere was first discovered by means of radio reflection experiments in 1924. Ionospheric exploration by radio probing has since been both developed in precision and extended in world coverage; in recent years such observations have been supplemented by rocket soundings. The ionosphere is stratified in various layers, and the radiophysicist has studied the regular ionic variations in these layers during the course of the day, during the seasons, and during the sunspot cycle of about eleven years. This has been done during the last quarter of a century, and, as a result, the subject of ionospheric forecasting has been developed. From a knowledge of past ionospheric events, together with an extrapolation related to the trend of the sunspot cycle, it is possible to estimate the kind of ionospheric conditions which are likely to obtain, say, three months ahead. From radio theory it is then possible to predict the range of wave-lengths which will be most successfully reflected by the ionosphere at any time of the day, over any length of radio circuit, and in any part of the world. All the radio wave-length planning in Britain for long-distance radio transmission, for both defence and civil services, is based on such forecasts.

The experimental radio-sounding of the ionosphere for ionospheric forecasting is almost invariably carried out by the pulse reflection method. This involves the accurate timing of the travel of the radio pulse up to the ionosphere and back. Since the pulse propagation in such a sounding is usually vertical in direction, we know that the radio waves travel into the ionosphere until they encounter a stratum where the electron density is sufficient to reduce the refractive index to zero. It is at that level that the waves are reflected. This is a simple result which follows from the laws of optics; however, the fact that electrons, rather than ions, are the effective charges in the ionosphere introduces a complicating factor into the relevant dispersion theory. Because of the influence of the earth's magnetic field, the ionosphere is a doubly refracting medium for radio waves. A radio pulse entering the ionosphere is therefore split into two components of complementary polarization, and we can speak, as in the case of the optics of uniaxial and biaxial crystals, of ordinary waves and extra-ordinary waves. In general, therefore, a single radio pulse is reflected as a doublet, because the ordinary and extra-ordinary components travel with different group velocities and are reflected at slightly different levels within an ionized layer. The conditions for reflection at vertical incidence for the ordinary wave component are expressed by

$$N = \frac{\pi m}{e^2} f^2 \qquad (1)$$

The corresponding relation for the extra-ordinary wave is

$$N = \frac{\pi m}{e^2} (f^2 - f f_H) \qquad (2)$$

Here N is the number of electrons, of charge e and mass m, per unit volume, f is the radio wave frequency, and f_H is the gyro-frequency with which free electrons rotate round the earth's magnetic lines of force. In Britain, for example, f_H is $1 \cdot 3 \times 10^6$ cycles per second. Equations (1) and (2) tell us therefore that radio pulses of, say, 4

megacycles per second (Mc/s) would require an electron density of 2×10^5 per cm^3 for reflection in the case of the ordinary wave and $1 \cdot 3 \times 10^5$ per cm^3 in the case of the extra-ordinary wave.

In routine radio-sounding, attention is usually centred on the ordinary wave, since this is the stronger component of the magneto-ionic doublet. Equation (1) therefore applies, and we note that the ionospheric electron density necessary for reflection at vertical incidence is proportional to the square of the radio frequency employed. By running steadily through the whole gamut of radio frequencies which the ionosphere will reflect at any time, it is possible to find the relation between the equivalent height of reflection h' and the frequency f. This (h', f) relation is the basic expression in ionospheric sounding, since from it we can find the critical penetration frequency of any particular ionized layer. For such a critical frequency we are evidently concerned with maximum ionization conditions and equation (1) therefore becomes

$$\mathcal{N}_m = \frac{\pi m}{e^2} f_c^{\,2} \qquad (3)$$

where $\mathcal{N}_m$ represents the maximum electron density in a layer and f_c the limiting frequency of penetration.

The two main layers in the ionosphere are the E and F layers; their lower boundaries are situated at heights of about 100 and 230 km respectively. In addition, there is situated, below the E layer, the D layer, which, while reflecting extremely

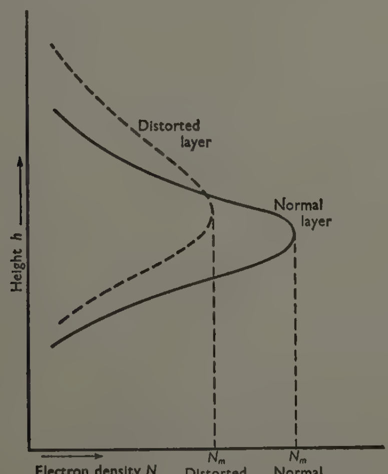

FIGURE 1 – *Illustrating how the maximum ionization density $\mathcal{N}_m$, of an ionized layer, can be reduced as a result of vertical differential expansion.*

long waves, acts mainly as an absorbing stratum for the shorter wave-lengths which must travel through it on their way to the E and F layers, where they may be reflected. Detailed observation has shown that the F layer consists of two overlapping strata, the F1 and F2 layers, which have quite different, and readily recognizable, characteristics. Generally speaking, the E and F1 layer variations are much as one would expect, assuming that, as is known to be the case, both layers are formed as a result of ionization by solar photons. The maximum ionization densities in both layers start to increase as the sun rises each morning, reach maxima very slightly after noon, and then decay as the sun sets. Also, the maximum ionization densities are greater in summer than in winter. Such regularities are not, however, paralleled in the F2 layer, which is, as has been indicated, the highest layer in the ionosphere. It is true that the F2 layer exhibits features suggesting a general solar control, in that its maximum ionization density is greater during the day than during the night, but when we examine its world morphology or its response to changing seasons, many anomalous characteristics become evident. The first F2 layer anomaly of this type to be recognized was that the maximum ionization density at noon is less in summer than in winter. To account for this anomaly we can picture the layer as being expanded in thickness, the expected ionization being present, but being spread out, for some reason, over a greater range of vertical height. This is illustrated in figure 1. The physical process is important, because it turns out to be the cause of many F2 layer anomalies.

So far we have been concerned with the regular behaviour of the ionosphere as exhibited in the temperate latitudes, where ionospheric sounding by radio began. However, since it was well known that auroral and other disturbances occurred in the upper atmosphere, particularly in high latitudes, it was decided, some twenty years ago, to undertake ionospheric observations at a site near the northern auroral belt. A convenient occasion was the Second International Polar Year 1932–3, when a British radio expedition was sent to Tromsö, in northern Norway, under the auspices of the Royal Society and of the Department of Scientific and Industrial Research. The British party worked at Tromsö for more than a year, and were able to lay the foundations of our knowledge of ionospheric conditions in high latitudes. It was quickly found that ionospheric disturbances accompanied auroral and magnetic storm

manifestations. It was found that during such conditions D layer absorption was intense, resulting sometimes in complete absence of radio reflection. It was generally found that when the absorption abated the F2 layer had also been affected, the value of the maximum electron density $\mathcal{N}_m$ having been reduced. Since, at the same time, the height of the layer had been increased, it was clear that some such upward inflation mechanism as that illustrated in figure 1 had been operative.

The results at Tromsö naturally prompted the search for ionospheric storm phenomena, associated with magnetic storms, at lower latitudes. As in so many other fields of scientific research, it was a case of knowing exactly what to look for. At temperate and equatorial latitudes there was little variation to be noted in the D, E, and F1 layers, but pronounced changes were noted in the F2 layer. Taking noon conditions first, it was found that there was a general tendency in temperate latitudes for $\mathcal{N}_m$ to be reduced, though less markedly than at high latitudes. This applies at most seasons, midwinter being the only exception. Near the equator, however, values of $\mathcal{N}_m$ were found to be increased during storm conditions, indicating possibly that a contraction of the F2 layer had occurred.

For many years it seemed odd that noon ionospheric storm conditions were so different in equatorial regions from those in high and temperate latitudes. In 1946, however, a further anomaly in the F2 layer was identified: it was shown that equinox noon values of $\mathcal{N}_m$ were more nearly related to magnetic latitude than to geographical latitude. This led to a more coherent picture of F2 layer morphology, over the world as a whole, for both quiet and disturbed conditions. Particularly, it was discovered that under normal conditions there is, at noon, a belt of low values of $\mathcal{N}_m$ centred on the magnetic equator. This is illustrated in figure 2, where the relations between $\mathcal{N}_m$ for the E, F1, and F2 layers and geographical latitude are shown for a line of longitude (75° W) corresponding to the east of North America. It will be seen that $\mathcal{N}_m$ for both the E and F1 layers is symmetrically related to the geographical meridian; whereas in the case of the F2 layer the curve is symmetrical relative to the magnetic equator, which, on the particular longitude concerned, lies about 11° south of the geographical equator.

Guided by the recognition of the geomagnetic control indicated in figure 2, it is possible to illustrate the effects of the same ionospheric disturbance at different sites. Using results for a number of stations, the ratio of the values of $\mathcal{N}_m$ under disturbed and quiet conditions (i.e. $D(\mathcal{N}_m)/Q(\mathcal{N}_m)$) is plotted in figure 3 as a function of geomagnetic latitude. We see at once that, in the higher latitudes in both hemispheres, $D(\mathcal{N}_m)$ is less than $Q(\mathcal{N}_m)$, but that, over a belt centred on the magnetic equator, the storm value of $\mathcal{N}_m$ is greater than the quiet day value. There are two further features of figure 3 to be noted. First, the belt over which $\mathcal{N}_m$ is increased during storm conditions is a little wider than the belt of the F2 layer equatorial anomaly illustrated in figure 2. Second, the belt of increased $\mathcal{N}_m$ values appears to extend into slightly higher latitudes in the southern hemisphere than in the northern hemisphere.

So far I have dealt with local noon values only, and yet figure 3 is derived from the results of stations of widely differing longitude, the actual times of observation differing between themselves by many hours. Such consistency as is shown among the results exhibited in figure 3 is due to the fact that an ionospheric storm is, very largely, a local-time effect, and the results for different stations during the same storm can be reconciled

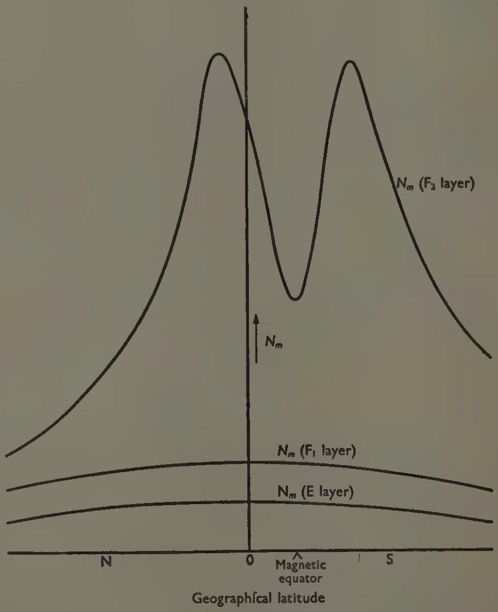

FIGURE 2 – *Showing how the maximum electron density, $\mathcal{N}_m$, varies at noon, along a line of longitude 75° W, in the E, F1, and F2 layers. While the E and F1 layers are symmetrically developed with respect to the geographical equator, the F2 layer is subject to a geomagnetic control.*

only if this is recognized. For medium-latitude stations the negative phase of the depression of $\mathcal{N}_m$ below normal travels round the earth with the sun. We can thus see how, as sometimes happens, the first negative phase of an ionospheric storm may be recorded at different longitudes on different dates. Actually, of course, the complete description of an ionospheric storm is the full record of the diurnal changes in $\mathcal{N}_m$ at all sites. These differ according to the geomagnetic latitudes of the stations, and will not be described here. However, the noon results are a fair guide to events during the day as a whole.

I now turn to consider the practical implications of these storm changes in the F2 layer, since this layer is the most important component of the ionosphere from the standpoint of radio communication. In short-wave transmission the choice of an optimum frequency is made by striking a balance between two conflicting considerations. In order to reduce D layer absorption, as high a working frequency as possible is desirable, yet it must not be so high as to pierce the F2 layer. But the higher the value of $\mathcal{N}_m$ in the layer and the lower the level of the layer maximum, the higher is the range of frequencies reflected. We can therefore see that in high and medium latitudes where, under storm conditions, the layer is expanded and elevated as illustrated in figure 1, the maximum frequency reflected will be much less than normal. On the other hand, the storm conditions in the equatorial belt are more favourable for short-wave radio reflections than the normal, for the increase in $\mathcal{N}_m$ is brought about by a vertical contraction of the layer, which results in the height of the layer maximum being slightly reduced.

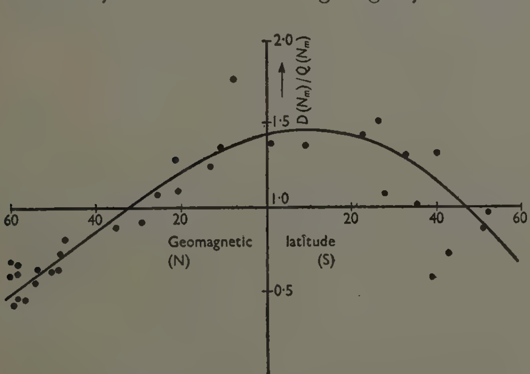

FIGURE 3 – *Showing the ratio $D(\mathcal{N}_m)/Q(\mathcal{N}_m)$ plotted with geomagnetic latitude. It will be seen that $\mathcal{N}_m$ is greater on magnetically disturbed days than on magnetically quiet days at low latitudes. The reverse is the case at higher latitudes.*

Thus both factors favour the use of high radio frequencies in communication in equatorial regions under storm conditions.

These purely scientific results can be readily confirmed from actual operations on long-distance radio circuits. During ionospheric storms the route of the radio waves from England to Canada lies along a great circle which is not far from the auroral zone. At such high latitudes the large reduction in the value of $\mathcal{N}_m$ is often accompanied by increased absorption and, when both effects are excessive, communication may be completely disrupted. On the other hand, the radio circuit to Cape Town may be, at the same time, only slightly disturbed. It is the liability of transatlantic radio circuits to periodic storm conditions that has underlined the urgency of the need for a new submarine telephone cable across the Atlantic. Meanwhile some mitigation of ionospheric storm difficulties can often be obtained by sending radio messages from England to North America by way of a relay station situated in equatorial regions.

To the general geophysical picture of auroral disturbances and magnetic storms, associated usually with the occurrence of sunspots, we can now add the phenomenon of the ionospheric storm. Auroral displays in high latitudes, however, are usually explained as due to the irruption of electrified solar particles into the earth's atmosphere along auroral belts centred round the two geomagnetic poles. Yet magnetic storm effects are of world-wide occurrence, and, as we have seen, disturbances in the ionosphere associated with magnetic storms can be detected even in equatorial regions, although the characteristics exhibited there admittedly differ from those found in higher latitudes. Our first major conclusion must therefore be that magnetic and ionospheric storm events cannot be the direct effects of the incoming solar particles and their associated auroral discharges, since the former can be world-wide while the latter are localized in the high latitudes. It should here be mentioned that there is still some doubt about whether ionospheric storms are always equally developed in the northern and southern hemispheres, even at the equinoxes. But it does seem adequately proved that the ionosphere can suffer storm perturbations at places where auroral disturbances are absent.

So far, I have been concerned with ionospheric storm morphology. I now turn to theoretical matters, where much less is certain. However, the basic physical mechanism of ionospheric storm phenomena has most probably been indicated by

D. F. Martyn. To understand this we turn again to figure 1, where are shown (*a*) a normal ionized layer profile and (*b*) a layer profile distorted by vertical expansion. Martyn has suggested that such layer deformation, which may be either an expansion or a contraction in vertical extent, is due to the ionization—electrons and positive ions alike—being moved up or down by electrodynamic forces. Let us consider in this connection, as the simplest possible example, the case at the equator, where the earth's magnetic field H is horizontal. Let us assume further that there is also operative a horizontal electric field, directed, say, from west to east. Physically we may say that the horizontal electric field will cause a horizontal current in the ionosphere and that such a current element will be acted on by the earth's magnetic field, causing it to move upwards. If either the electric or magnetic field is reversed the motion will, of course, be downward. We thus see that, if the F2 layer is subject to electric forces in the presence of the earth's magnetic field, the phenomenon of drift motion arises because the ionized layer itself constitutes an electric conductor which is free to move. Generally, we may say that, if an electric field E, acting from west to east, operates in an ionized medium where the earth's magnetic intensity and dip are H and φ respectively, the horizontal southward drift u, and the vertical upward drift v, of the F2 layer ionization, are given, approximately, by

$$u = -\frac{E \sin \varphi}{H} \quad \text{..........(4)}$$

and

$$v = \frac{E \cos \varphi}{H} \quad \text{..............(5)}$$

These, then, are the basic equations of Martyn's theory of F2 layer distortion. He has applied them to explain the F2 layer behaviour under normal as well as storm conditions. But two further points must be mentioned. To get either the vertical expansion or distortion of an ionized layer, the vertical drift v must vary with height. If v is constant, the layer is merely moved bodily upwards or downwards. A basic question also is the origin of the horizontal electrostatic forces, whose existence has so far been only postulated here. To account for these, Martyn points out that the lower ionosphere (probably the lower level of the E layer) is the seat of large currents which are responsible for both the quiet-day and the disturbed-day magnetic variations, though their world configuration is different in the two cases. Martyn considers that both the normal-current system and the storm-current system in the lower ionosphere give rise to electrostatic forces which, together with the earth's permanent magnetic field, are responsible for both vertical and horizontal movements of ionization, and that it is due to the different world configurations of these electrostatic lines of force that the F2 layer effects under normal and storm conditions are different. Much work, however, remains to be done in developing these basic ideas to a full understanding of the different manifestations of F2 layer distortion at all times and at all places.

Perhaps a further comment may not be superfluous. It was at one time thought that the ionosphere was a quiet place, and that electrons appeared and disappeared at precisely the same spot. Recent work has clearly shown that this is not the case. The radio tracking of patches of ionization has indicated that horizontal motion undoubtedly takes place, while, as we have seen, ionospheric storm phenomena also indicate substantial movements of ionization in a vertical direction.

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The Muspratts and the British chemical industry

D. W. F. HARDIE

James Muspratt is justifiably regarded as the founder of the British heavy chemical industry, and members of his family, the history of which is here reviewed, played a prominent part in it for over a century. Particular mention is made here of James Sheridan Muspratt, who established a name for himself as a talented analyst and teacher of chemistry. His great dictionary of chemical technology was for many years a standard work throughout the world and even today is a valuable source of information about nineteenth-century practice.

According to a family tradition, the Muspratts were originally immigrants from France. Official records at Somerset House, London, show that in the first half of last century there were numerous bearers of the name in the southern counties of England and in London. Although details are lacking, it seems probable that the Muspratts who appeared in Dublin directories towards the end of the eighteenth century were all members of a family group which had recently migrated from England. In the Irish capital, where the brewing industry had already reached considerable dimensions, they plied their trade of cork-cutting. One member of the Dublin branch, John Petty Muspratt, became a banker in London and attained to an influential position as a director of the East India Company, being elected by the private trade interest first in 1825 and again in 1930 [1]. Evan Muspratt, brother of the East India director, had three children—a daughter who in later life resided in America; George, of whom nothing is known; and James (b. 1793) [2].

Evan Muspratt probably gained sufficient income from his cork-cutting business to give his son James as good an education as early nineteenth-century Dublin could offer. Details of James's life-history begin to emerge only from the time of his father's death in 1810. Following her husband's death, James Muspratt's mother married John Corley of Dublin in 1811, but survived only a few months thereafter [3]. The death of both his parents, and his mother's remarriage, must have had a profound effect on the lad of eighteen years, and flight from bitterness and grief may be in great part the explanation of his seeking adventure in the war-torn Spanish peninsula [4]. Having returned to Dublin as a deserter from the Navy, James for a time joined a gay coterie associated with the Irish stage, thus developing a taste which he was to indulge to the full in later years.

In the first decades of last century, Dublin was, by the scale of chemical industry at that period, an important chemical manufacturing centre, particularly for sulphuric acid. In 1819 James Muspratt married Julia Connor, and no doubt the prospect of establishing a family provided the immediate urge for young Muspratt to forsake for a time his social life and to apply himself to the business of making chemicals. This he did in partnership with Thomas Abbot, a drug and general merchant. Friendship with the family of the future Sir Robert Kane, acid manufacturers in Dublin, may have influenced Muspratt in this.

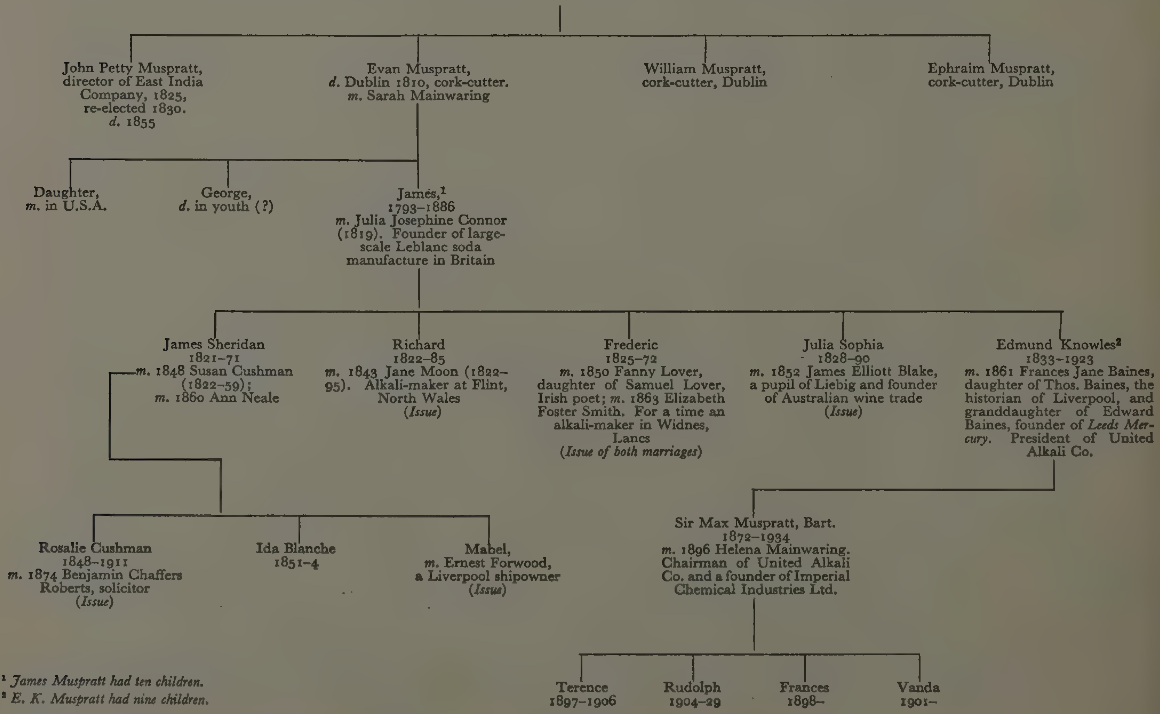
In 1822, an Act of Parliament reducing by half the import duty on barilla was threatening seriously to reduce the advantage, *vis-à-vis* their London competitors, which Merseyside soapboilers derived from their use of untaxed native kelp. In conjunction with the circumstance that several years earlier, Tennant, at Glasgow, and Losh and Lord Dundonald, at Newcastle, had introduced on a small scale the manufacture of soda from salt by the Leblanc process, this Act was of great significance. There is some, but far from conclusive, evidence that Muspratt may have experimented with the Leblanc process in Dublin; whether he did so or not, 1823 found him in Liverpool making black ash and applying all the force of his Irish wit to persuading the neighbouring soapers to use it in place of the traditional natural alkalis. In this venture he was ultimately entirely successful, and the scale to which his operations rapidly attained justifies his being regarded as the effective founder of the British heavy chemical industry [5].

Nevertheless, despite all the distractions of industry and commerce, James Muspratt's interests continued to lie in the direction of travel and the

social life. As soon as, and whenever, circumstances permitted, he fled from his factories at Liverpool and Newton to seek the companionship of his friend Justus von Liebig in Germany, or the society of artists and other sun-seeking fugitives in Rome and Florence. The years of his fully active industrial life were comparatively few, extending only from the hard and hated early days in Dublin (1819–22) to 1850, but those were the years when the richest harvest was reaped from the old type of soda-making in this country. It was a period in which, despite the activity of numerous inventors, few far-reaching technical modifications took place in methods of chemical manufacture; the primitive state of chemical engineering made such progress difficult. In 1850, James Muspratt, harassed by the growing complications of carrying on the industry in the old way and by mounting claims for compensation for damage due to waste hydrochloric acid, and even by demands for closure of his factory at Newton, largely withdrew from active business.

When James Muspratt retired from alkali-making, three of his sons—James Sheridan, Richard, and Frederic—had all had experience in the soda factories. Soon after 1850 Richard established himself, in partnership with Huntley, at Flint in North Wales, where for many years he operated one of the largest Leblanc works in Britain. Frederic, with his father's support, for a time applied himself with no great enthusiasm to alkali-making at Widnes, ultimately relinquishing control to his younger brother Edmund Knowles Muspratt, who, fresh from Liebig's laboratory at Giessen, set about vigorously reorganising the Muspratt soda-making interests. When, in 1890, the Muspratt concerns in Liverpool, Widnes, and Flint, together with most of the Leblanc works in Britain, were merged in the United Alkali Company, Edmund Knowles Muspratt[1] assumed a leading part in the new concern, in which he was a dominating influence up to the period of the first world war, when total blindness afflicted him. By this time his son Max, who was created a baronet in 1922, was active in the United Alkali Company, and when, in 1926, Imperial Chemical Industries Limited was formed, Sir Max Muspratt was one of the leading industrialists

[1] E. K. Muspratt was one of a number of prominent citizens who established the University College, later University, of Liverpool; he was the first President of the Council when the University Act of Liverpool came into effect in 1903. He was also Pro-Chancellor, and he supplied the funds for the chemical laboratory.



[1] *James Muspratt had ten children.*
[2] *E. K. Muspratt had nine children.*

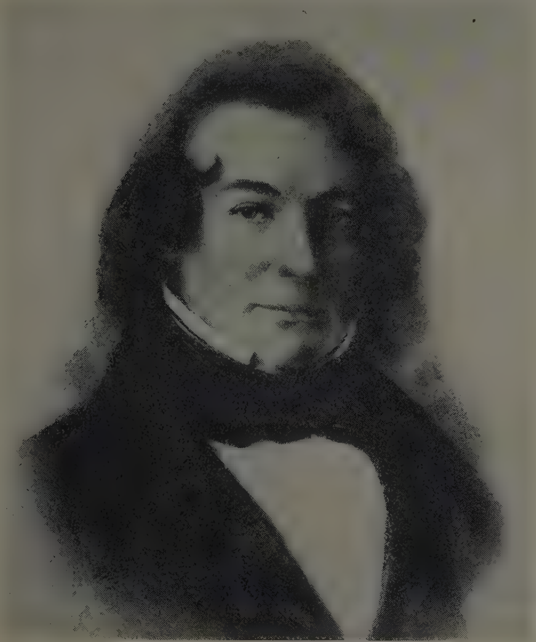


FIGURE 1 – *James Muspratt.*

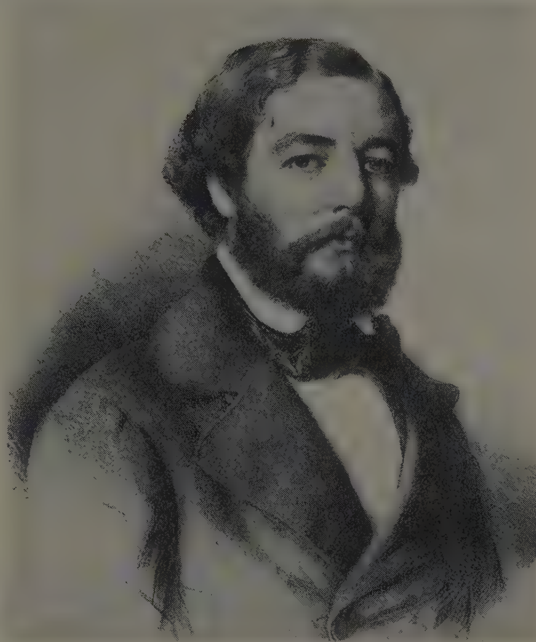


FIGURE 2 – *James Sheridan Muspratt.*

who participated in its founding. Thus, from the days of James Muspratt's small-scale chemical-making in Dublin to the third decade of the present century, the Muspratt connection with the British chemical industry was continuous.

Of the sons of James Muspratt, James Sheridan, whose story follows, was not the most successful in the commercial and industrial field. His interest was less in chemical industry than in chemistry as a science: his influence on industry was indirect, but nevertheless it was not unimportant, and he deserves his own place and recognition in its history. The name of Sheridan was a later assumption, prompted by admiration for his father's friend, James Sheridan Knowles, an actor and author who was a cousin of Richard Brinsley Sheridan, the dramatist. In what follows we shall use the name of Sheridan for the son to distinguish him unequivocally from his father.

Sheridan received his early education at private schools near his home in Bootle, and at the age of about thirteen began travels in France and Germany [6], probably in charge of one of his tutors. Through the Tennants of St Rollox, James Muspratt senior was acquainted with Thomas Graham (1805–69), then professor of chemistry at the Andersonian College in Glasgow; to this teacher he sent Sheridan in 1836, there then being in Liverpool no institution giving chemical education. Sheridan remained in Glasgow for about nine months, until Graham was elected (April 1837) to the chair of chemistry at University College, London. One of the testimonials Graham presented when canvassing his appointment was from the Liverpool alkali-maker [7].

With his brother Richard, Sheridan followed Graham to London, and there became interested in the small ammonia-soda plant being worked in Whitechapel in 1838 by Hemming and Dyar [8]. As a result of Graham's and his son's enthusiasm (restrained on Graham's part) for the new process, James Muspratt employed it for a time at his Newton works—a technological venture that lost him some £8000 [9].

Graham's pupil, Lyon Playfair—who achieved some celebrity in nineteenth-century academic chemistry—worked for a short time in the laboratory of Muspratt's factory. In the autumn of 1839 James Muspratt proposed to Playfair that he should advance him part of the requisite capital if Playfair would take Muspratt's sons into partnership in a chemical manufacturing concern. In a shrewdly couched letter [10] Playfair thanked Muspratt for his generosity, but made it clear that he must be under no obligation, if he were to

accept it, to take the younger Muspratts as partners, and there the matter rested.

The great potentialities of a chemical export trade from the Mersey to the United States must have been evident to James Muspratt, even before a visit he made to America in 1838. In the summer of 1840, he sent his son Richard to New York, and, in the same year, Muspratt and Tennant shipped the first cargoes of soda-ash to America [11]. From this beginning grew, in the course of the next few decades, the great nineteenth-century chemical export trade from Britain. By 1850, about 60 per cent of the soda-ash made in Britain was being shipped across the Atlantic.

In the summer of 1841, following his brother's return to England, Sheridan was sent by his father to Philadelphia, where he was set up in business with one of his father's American friends, James McHenry, the firm acting as a selling agency for James Muspratt. In the first six months, Sheridan sold only 25 dollars' worth of soda-ash and 2500 dollars' worth of soda crystals. He was optimistic, however: he calculated that 'there will be $150 000 worth of ash sold' in the year to come. He conjured up visions of the commission he was to receive from these sales: 'I know that what I spend will be earned—the sweetest reflection a man can have' [12]. Sheridan was certainly spending. His sojourn in the United States cost his father several thousand pounds and did not notably advance Muspratt's commercial connection in Philadelphia. In 1842 Sheridan sailed for Liverpool.

On the occasion of the British Association's meeting at Liverpool in 1837, James Muspratt made the acquaintance of Justus von Liebig, who was one of the distinguished foreign visitors [13]. This acquaintance soon warmed into friendship. There followed, as we have mentioned, much coming and going between Giessen and the great house, Seaforth Hall, which Muspratt had built on the Mersey sand-dunes. In 1843 Sheridan's father committed him to the care of his friend Liebig. At Giessen, while entering with characteristic zest into the student life of the university, Sheridan applied himself with energy to his studies. Liebig, impressed by the ability of his pupil, entrusted him with the elucidation of the composition of certain metallic sulphides. For this work, Sheridan was awarded the degree of Doctor of Philosophy, a distinction then rarely held by foreigners. Thereafter, Sheridan for a time attached himself to A. W. Hofmann at the Royal College of Chemistry in London. He carried out with Hofmann an investigation which led to the discovery of toluidine.

At the 1837 meeting of the British Association, Liebig was asked to make a report on the state of organic chemistry. This request led, in 1840, to the publication of one of his most important works —*Die Chemie in ihrer Anwendung auf Agrikultur und Physiologie*. From that time dated Liebig's experiments to determine the nature and amounts of substances removed from the soil by growing plants, a practical consequence of which was his use of fertilizers to replace these substances. In 1845, James Muspratt took out on Liebig's behalf a British patent for the manufacture of soil additives [14]. At Muspratt's Newton works, Sheridan, with his brother Richard, made experimental amounts of the patent fertilizers. 'The entire revolution' in agriculture, confidently predicted by Sheridan, did not materialize: the fertilizers, subjected to incipient fusion in a furnace, were too insoluble to be effective.

This fertilizer venture almost brought about a serious rift in relations between Liebig and his English friends. In a confidential moment, Sheridan communicated to Dr Petzhold, a friend from his Giessen days, the formulae of the fertilizer mixtures made at Newton. By an unfortunate circumstance Liebig came to know of this indiscretion. He wrote angrily to James Muspratt: 'There lies in this an abuse of confidence placed in him [Sheridan] which must have the effect of immediately removing him from the situation he occupies. I should never have believed this had not Dr Petzhold sent me (for another purpose) the copy written by Dr James's own hand. . . . Dr James has by his criminal indiscretion cut off the possibility of introducing myself the fabrication of the manures into Germany. . . . I cannot tell how afflicted I am' [15]. Liebig's friendship survived his affliction, however; the affair was soon forgotten, along with the utter failure of the fertilizers.

Like his father, Sheridan was greatly attracted by the stage. On the occasions of visits to Liverpool by Charles Dickens' amateur company he acted as organizing secretary. In March 1847 Sheridan attended a performance of 'Much Ado about Nothing.' It was the first appearance in Liverpool of the then famous American actress, Charlotte Cushman, and her sister Susan. Shortly afterwards the Cushman sisters were guests at a fancy-dress ball at Seaforth Hall [16]. Susan's beauty and the tragedy of an early and disastrous marriage made her doubly attractive; on 22nd March 1848, Susan Cushman, then a widow, married Sheridan Muspratt, an event which brought

the expressed approval of Alfred Tennyson [17].

In the summer of 1848, in a stable adjoining his Canning Street house, Sheridan established the Liverpool College of Practical Chemistry, his patron being no less a person than the Prince Consort himself. Liebig gave this enterprise his public blessing, testifying to Sheridan's suitability for 'the office of Professor.' The object was 'to afford at very moderate expense, *practical* instruction to students in organic, inorganic, and blowpipe chemistry, and to create chemists capable of investigating and reporting upon all subjects relating to agriculture, arts, manufactures, etc.' The term was divided into two sessions, each of eighteen weeks. Students were required to supply their own small apparatus, but reagents and gas were supplied by the professor; there was the facility of 'access to a German and English library of the best chemical works of the day' [18]. Eighteen students were soon regularly at work.

While at Giessen, Muspratt had translated into English—as 'Plattner on the Blow-pipe'—Plattner's *Probierkunst mit dem Löthrohre*, the standard work on blowpipe chemistry. This translation attracted considerable attention and probably occasioned the request, in 1854, by George Blair, a Glasgow publisher, that Sheridan should prepare an encyclopaedic work on applied chemistry, 'Chemistry, Theoretical, Practical, and Analytical, as applied to Arts and Manufacture.' The work was published in monthly parts. The editing fell heavily on Martin Murphy, an able student from Limerick, who had decided that his vocation was chemistry and not the priesthood, and who had become Sheridan's righthand man at the College. For two years Murphy worked sixteen hours a day on the dictionary. Before it was complete, Sheridan's young wife died, on 10th May 1859, an event which had a profound effect on him; for some months no new parts of the dictionary appeared. When finally published in volume form it was dedicated to J. B. Dumas and to his father's friend, the Irish chemist Sir Robert Kane [*Endeavour*, **4**, 91, 1945]. The book was an immediate success in this country and on the Continent; in America, Harvard honoured the author by conferring on him the first honorary degree of M.D. bestowed by the university on a British subject. Muspratt's dictionary was soon translated into several foreign languages, including Russian; the latest German edition appeared as recently as 1927.

About a year after the death of his wife Susan, Sheridan married Ann Neale of Rainhill, near Liverpool, who survived him. He died on 3rd February 1871 in his forty-ninth year. He was a chemist of talent rather than of genius; his researches were largely skilful analytical performances, and he failed to establish himself in a field of his own [19]. Lacking commercial ability, he chose, in place of the life of cultured idleness that could readily have been his, to be an energetic pioneer in teaching the practical science which, allied with great business acumen, had brought his father fame and fortune.

The author gratefully acknowledges his indebtedness to Mrs Permewan of Liverpool, grand-daughter of James Muspratt, for permission to make use of material from documents in her possession.

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Plant cytology and the electron microscope

A. FREY-WYSSLING

Plant cytology now covers a very wide field, and includes the study of such bodies as cell walls, cytoplasm, plastids, mitochondria, nuclei, and chromosomes. The finest structure of these has not yet been fully elucidated, but in the region of size corresponding to the range between very large molecules and the smallest particles visible by direct optical methods the electron microscope has yielded a good deal of information. This instrument may, indeed, be said to link morphology and biochemistry and to have given cell biology a new unity.

CELL WALLS

The cell walls of plants are covered by a tough membrane which ontogenetically consists of two layers—the primary and secondary walls. The primary cell wall envelops the protoplasm of young cells during growth; towards the end of cell differentiation, however, this thin membrane becomes reinforced by the deposition of a second, thicker one having a laminated structure.

When examined by the optical microscope the primary wall appears homogeneous. It contains only a small proportion of cellulose (about 5 per cent) but large proportions of pectins and hemicelluloses, some lipophilic substances such as waxes, and even some protein. The protein disappears before the primary wall stops growing, suggesting that the latter at first contains living protoplasm but that this separates from the membrane at quite an early stage. The primary cell wall apparently grows by some form of intussusception, for it enlarges its surface considerably during cell differentiation. The study of how a solid membrane extends its area in this way is a very interesting one.

The secondary wall is quite different from the primary. It contains a high proportion of cellulose, usually more than 50 per cent; it is this which makes it the raw material for pulp-making. Under the polarizing microscope it displays a remarkable anisotropy. It grows by apposition, and for this reason is generally laminated, with layers parallel to the cell surface. It often shows striations arranged helically with respect to the axis of the cell. It has characteristic perforations, known as pits; these are not, however, open pores between adjacent cells but are separated by the pit membrane (figure 1), which represents the homogeneous primary wall. It was long a matter of controversy whether the pit membrane is continuous or contains perforations too small to be visible through the optical microscope. This question is an important one, for the answer determines whether the protoplasts of neighbouring cells are separated from each other or are in contact, i.e. whether they resemble animal cells or whether their interrelationship depends wholly upon the exchange of materials across an inanimate membrane.

The electron microscope enables the fine structure of the cell walls to be seen, and examination is much facilitated by the fact that whereas cellulose is chemically very resistant the other constituents of the cell walls are readily removed by dissolving or hydrolysing them. In consequence the primary cell wall can be reduced by maceration to a very thin film, which yields striking pictures after shadowing with chromium (figure 3).

Such pictures not only show that the cellulose consists of submicroscopic strands but reveal a most surprising structure. The strands are not laid down one upon another but appear to be interwoven. Sometimes there are two main directions of orientation, and then the appearance resembles the weave of a textile fabric (figure 2). The individual strands are separated from each other by relatively wide spaces, and it is these which, in the original

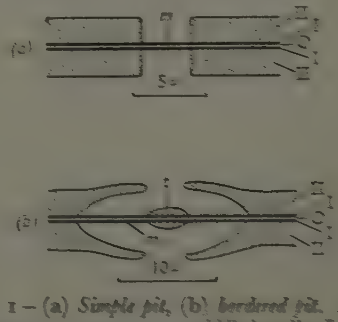

FIGURE 1 – (a) *Simple pit,* (b) *bordered pit. Key:* m = *pit membrane;* t = *torus;* o = *middle lamella;* I = *primary cell wall;* II = *secondary cell wall.*

cell wall, contain the highly hydrated, non-cellulose constituents. In electron micrographs these spaces seem to be very much reduced, but this effect is a consequence of the mode of preparation of the material and of the nature of the instrument itself: the macerated material has to be dried before examination, and the electron microscope has a considerable depth of focus.

The cellulose strands revealed by the electron microscope have been called microfibrils [7]. By ultrasonic irradiation they can be split into even finer threads which must be elementary fibrils, because they correspond to the crystalline micellar strands disclosed by X-ray diffraction analysis.

In contrast with what is seen in the primary cell wall, the microfibrils in the secondary wall are mostly parallel with each other (figure 4); this is why this wall is denser and much richer in cellulose. Because of this structure the secondary wall can easily be split into fibrils, which represent bundles of microfibrils and are visible through the optical microscope. The so-called slip-planes (figure 4), characteristic of plant fibres, are another consequence of this structure.

The growth in area of the primary cell wall can be followed by means of the electron microscope. During mitosis the membrane appears within the cell plate, where it is formed by deposition on either side of the amorphous middle lamella. Even at this early stage it consists of interwoven microfibrils, which make contact with the primary wall of the mother cell. In the region where the longitudinal wall will be joined the texture is loosened and the microfibrils at the

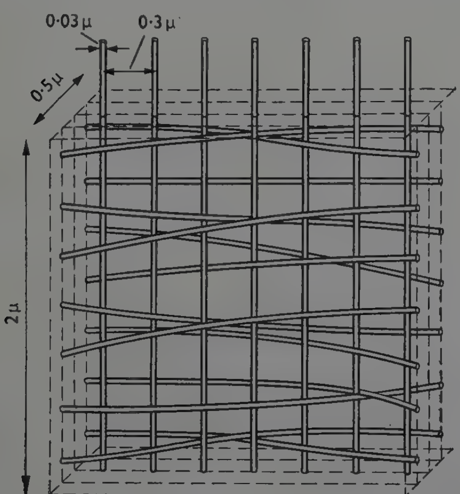

FIGURE 2 – *Texture of cellulose microfibrils in the growing primary cell wall* [3].

border of the newly formed cell plate become plaited into the weakened fabric of the lateral wall (figure 9). The latter finally breaks along a line between the attached primary membranes of the two daughter cells.

The walls of the new cells will for a time increase by intussusception, representing a mosaic growth, as indicated by the fact that in certain areas the interfibrillar spaces increase considerably, so that the texture is strikingly loosened (figure 10). Later these areas are repaired by the insertion of new microfibrils (figure 11). This type of growth is particularly evident when the cells increase their girth. In the longitudinal direction it is immediately followed by bipolar growth at the tips [10]; this is characterized by rapid addition of new microfibrils, at both ends of the cell, to the existing primary cell wall (figure 12). While growth at the tips goes on, the main part of the cell begins to consolidate its wall by reinforcing it with microfibrils arranged in parallel fashion (figure 5); this process begins at the edges of the cells and continues until the inner surface is covered with the secondary wall. The pit areas, however, do not share in this growth in thickness; there the primary wall becomes differentiated into submicroscopic sieves of an astonishingly beautiful texture (figures 7 and 8). Through the pores of these pit membranes submicroscopic strands of cytoplasm connect the neighbouring protoplasts. This is why the pits of adjacent cells always correspond, even though the optical microscope makes it appear that they are separated by a continuous membrane.

The internal structure of the microfibrils can be investigated by X-ray diffraction methods after they have been split up into elementary fibrils either by ultrasonic irradiation or by chemical means. The cross-section of the elementary fibrils corresponds to about one hundred cellulose molecules; the fibrils have a crystalline core, covered with para-crystalline cellulose arranged in a less orderly pattern (figure 16). The most hydrophilic plane (101) of the crystal lattice runs parallel with the surface of the protoplasm; it does not coincide with the plane of the ribbon-like cellulose chain. On sedimentation from suspension all the elementary fibrils are deposited on their (101) plane; moreover, they display a tendency towards lateral association (figure 6). All the evidence is, therefore, that they are flat. The probable structure of the microfibrils, as seen in cross-section, is indicated in figure 16, which illustrates that the organization of the plant cell wall can now be traced with some

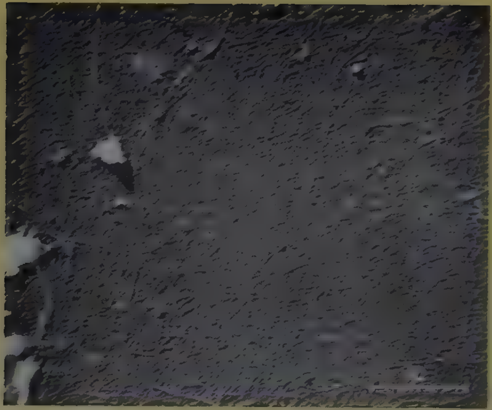

FIGURE 3 – *Primary cell wall of a linen fibre* [7].

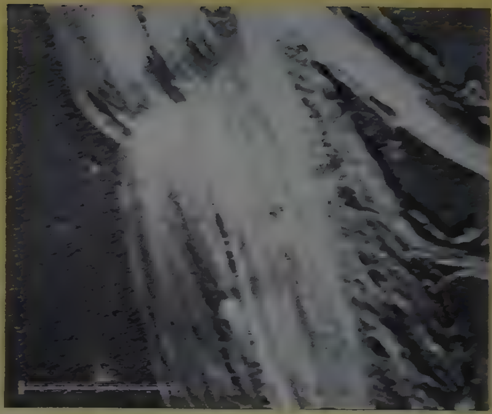

FIGURE 4 – *Secondary cell wall of a cotton fibre* [7]. *A 'slip-plane' is visible at top left.*

FIGURE 5 – *First deposition, in an oat coleoptile, of secondary microfibrils, arranged parallel with each other along the edge of a parenchyma cell* [10].

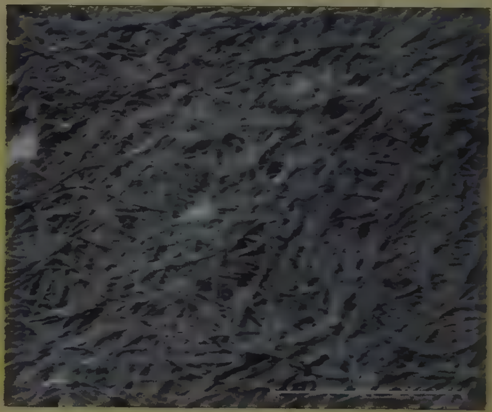

FIGURE 6 – *Lateral fasciation of microfibrils in the mesophyll cell walls of a tulip bulb* [2].

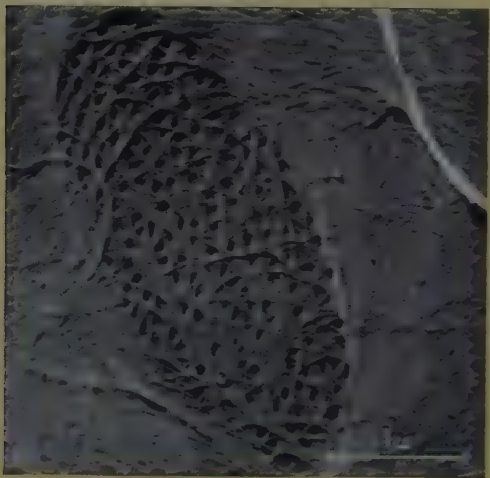

FIGURE 7 – *Pit membrane of a simple pit in the radicle of maize. (By courtesy of Dr K. Mühlethaler.)*

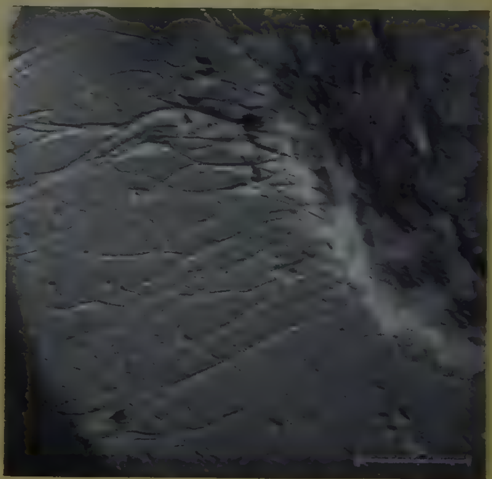

FIGURE 8 – *Pit membrane of a bordered pit from the wood of fir* [4].

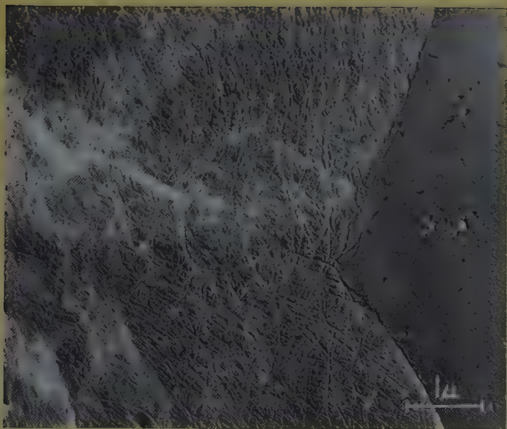

FIGURE 9 – *Fusion of the cell plate with the lateral primary wall after mitosis, in the meristem of an oat coleoptile* [6].

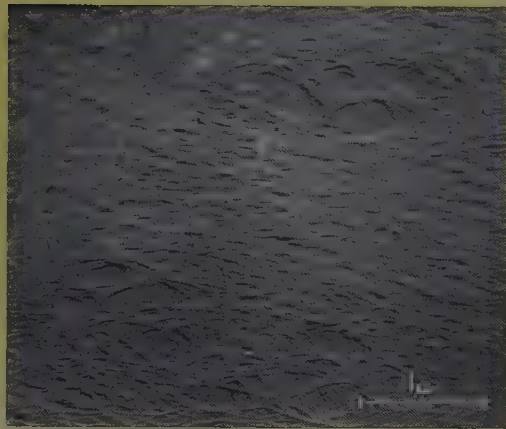

FIGURE 10 – *Mosaic growth of the primary wall in an expanding cell in the radicle of maize* [8].

FIGURE 11 – *Intussusception in the primary wall of an expanding cell in the coleoptile of maize* [7].

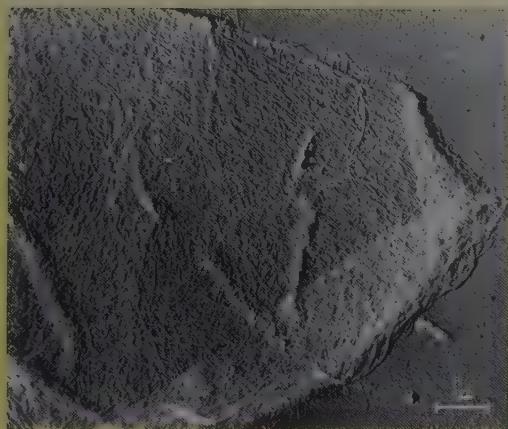

FIGURE 12 – *Tip growth of the primary wall; elongating cell in an oat coleoptile* [10].

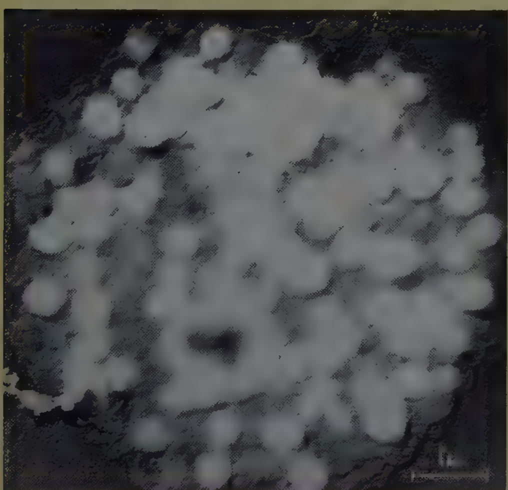

FIGURE 13 – *A chloroplast of spinach* [9].

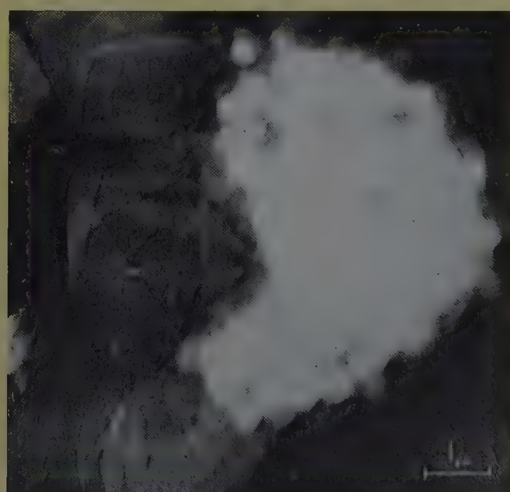

FIGURE 14 – *Unilateral swelling of a chloroplast of spinach* [9].

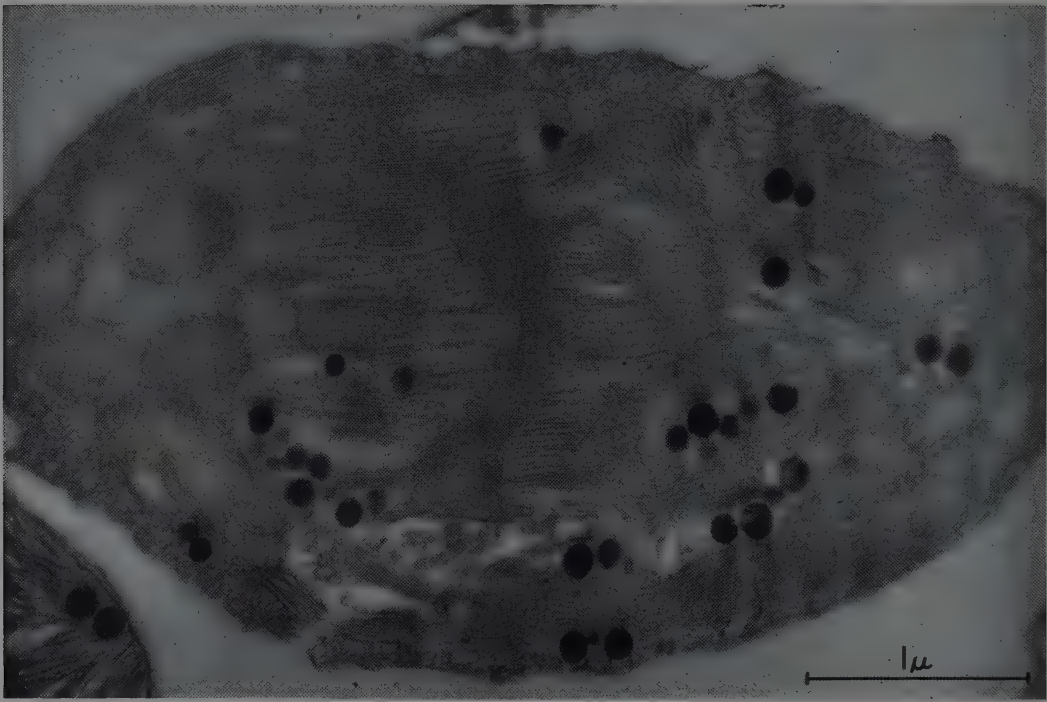

FIGURE 15 – *Ultrafine section of a chloroplast of* Aspidistra. *(By courtesy of Dr E. Steinmann.)*

confidence not merely as far as the microfibrils and elementary fibrils, but even down to the most important molecular constituent, the cellulose chain.

CHLOROPLASTS

In the chloroplasts, the sites of photosynthesis, the chlorophyll is not uniformly distributed but is concentrated in the so-called grana, which are embedded in a colourless stroma (figure 13). Chlorophyll shows a characteristic fluorescence in ultra-violet light, in which the grana appear a deep red against a black background; in this way the stroma can be shown to be free of chlorophyll.

The grana are arranged in piles (figure 17), each consisting of a series of submicroscopic lamellae [5]. This lamination is beautifully demonstrated in ultra-fine sections cut with the Sjöstrand microtome (figure 15). The lamination is so regular that it yields X-ray patterns corresponding to a period of 250 A [1]; it is caused by piles of flat follicles which are capable of swelling [9]. Their membranes consist of globular particles, and the fine

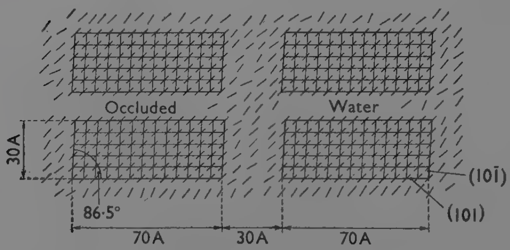

FIGURE 16 – *Section across a microfibril of native cellulose composed of four elementary fibrils. A core of crystalline cellulose chains is embedded in paracrystalline cellulose.* (101) *and* (10Ī) *are planes of the crystal lattice* [3].

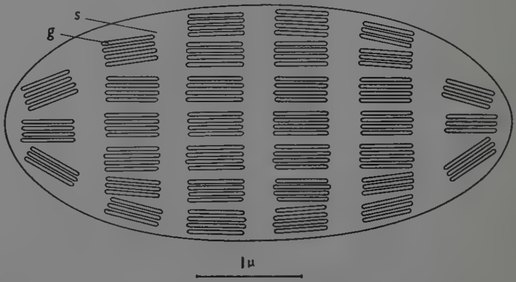

FIGURE 17 – *Arrangement of the grana in the chloroplast. Key:* g = *grana with a submicroscopic lamination;* s = *stroma.*

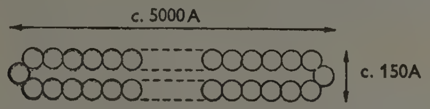

FIGURE 18 – *Macromolecular structure of one of the follicle-like double lamellae in the chloroplast grains* [9].

structure of the follicles is illustrated in figure 18. These globules represent macromolecules of the chromolipoprotein which is responsible for the capture of light energy by the chloroplasts; it is rich in pigment, containing more than 30 per cent of chlorophyll by weight.

The stroma, too, is laminated (figure 15), but its lamination is less regular than that of the grana [1]. Generally speaking, the lipoproteins of the stroma are so unstable that they can scarcely even be fixed without decomposition; in figure 15, showing a preparation fixed with osmium tetroxide, the black spheres probably represent lipids resulting from decomposition of lipoprotein.

No conspicuous membrane around the chloroplast can be demonstrated. It is apparently separated from the cytoplasm by a two-layer phase boundary similar to that in the plasmalemma or at the surface of large mitochondria. When the electron microscope seems to reveal distinct films as boundaries to the chloroplasts, these must be looked upon as artifacts due to coagulation of the lipoproteins by improper fixation. Figure 14 shows such an effect produced during the isolation of a spinach chloroplast in sucrose solution of appropriate strength; although the structure of most of the chloroplasts was conserved the one illustrated appears to be unilaterally swollen. Protein both of the stroma and of the grana has been transformed into membranes like blown-up bladders; on drying, these have fallen into the folds typical of coagulated protein membranes when viewed by the electron microscope.

CONCLUSION

It is evident that the cell walls and the chloroplasts of plants each have their own structural characteristics. The cell membranes are built on a fibrillar principle, which appears in the macroscopic fibre strands, in the microscopic fibre cells, in the microfibrils and elementary fibrils, and finally in the cellulose molecules themselves. Although the diameter of a cellulose molecule is a million times smaller than that of a fibre strand, the architecture is fundamentally the same in both.

Linear arrangements of filaments seem to be a general principle in the skeletal substances of many types of organism. It appears not only in the cellulose of plant cell walls, but in the chitinous cell walls of fungi, in the chitinous skeletons of arthropods, in the siliceous framework of sponges, and even in the collagen which forms the connective tissue, bones, and skin of vertebrates. This general principle of construction is doubtless related to the high tensile strength of the fibrillar elements used.

In chloroplasts, on the other hand, a laminar principle is characteristic. Their location is in the blades of leaves; their shape is flat; and their submicroscopic structure is characterized by lamellae composed of molecular films of macromolecules. Here again a single characteristic morphological principle is encountered over a wide range of size. This type of structure seems obviously correlated with the capture of light energy, the principal task of the chloroplasts. The retinal rods in the eye, it may be remarked, show a similar submicroscopic lamination.

There are, however, many other structures encountered in cytology which have a laminated structure but yet have nothing to do with light absorption. As examples may be mentioned the myelin sheath of nerves, the ergastoplasm of glands, and the big mitochondria in the kidney, pancreas, and other organs. A high rate of metabolism is a common feature of most of these laminated structures, and the general purpose of lamination seems to be to facilitate exchange of energy and metabolites.

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The colours of animals

H. MUNRO FOX

The colours of animals are due either to pigments or to the physical structure of the integument. Most pigments are synthesized by the animals, but one important group—the carotenoids—is derived from plant food. The structural colours are caused by Tyndall scattering or by interference of light. This article surveys the principal types of coloration in animals.

The coloration of animals is of great interest from several points of view. We may consider the function of the colour in the life of the animal, its chemical or physical nature, and whether colouring matters are synthesized by the animal or are derived from its food. In this article we shall be concerned mainly with the second and third of these aspects, but we may begin by briefly considering function. We must remember, however, that here our interpretations must often be speculative. Moreover, some animals can see colours as we do, others see colour that we cannot see, and yet others are colour-blind; clearly all this must be taken into account in any interpretation.

Colours and patterns may make animals either inconspicuous or conspicuous. Inconspicuous colouring enables predator or prey to escape notice: examples are the polar bear and the hare. Often the shape, which would betray the animal, is broken up by stripes, as in the tiger, or by spots as in the serval (figure 7). In a few cases the animal assists by changing its colour: a tree-frog can become more green or less green (figure 13). Conspicuous colouring is also found, and this too has its uses. It may enable animals to recognize their own kind, for mating or flocking: perhaps the moth in figure 5 and the barbet in figure 10 are examples of this. In some, for instance the peacock, the male alone is conspicuous, and he displays to the female. In the salamander (figure 9) the striking colour pattern may be a warning of an unpleasant taste, or in the sea-anemone (figure 11) of the power of stinging. In other cases the colours seem to us to be accidental, and we wonder if the beetles' metallic tints (figure 1), the lobster's blue and red (figure 6), the green and orange lower side of crabs (figure 12), the flamingo's pink (figure 14), or the colours and patterns of scallop shells (figure 15) can be of any use to their owners. Haemoglobin is red and happens to colour a few animals, such as the earthworm, the crustacean in figure 16, and so-called white man, in whom, however, blushing may be of significance. We are certain at least that the colour of the mother-of-pearl inside shells (figure 4) is useless, for in life it is invisible, and the brilliant seamouse (figure 3) lives buried beneath mud.

The colours of animals are due either to pigments or to structure. Pigments are substances which, owing to their chemical nature, absorb light of certain wavelengths and reflect light of others, and so are coloured. The red robin, yellow canary, green caterpillar, and blue lobster are coloured by pigments. But there are brilliant colours that are due not to pigments but to the physical nature of structures at the surface of animals. These are spoken of as structural colours [1], and we will consider them next.

It was Tyndall, nearly a century ago, who explained the blue colour of the sky; it is blue for the reason that very small particles in the upper air scatter back to us a higher proportion of the short waves of sunlight than of the long waves. Feathers are blue (figure 10) for a similar reason, and so are blue eyes and the blue face of a mandrill. The green colour of feathers (figure 10) is due partly to the same cause. An outer layer of yellow pigment absorbs the blue but allows the green, yellow, and red components of white light to enter the feathers. The green light is scattered by minute air spaces in the translucent feather substance to a greater extent than the longer-wave yellow and red, which are absorbed by a black internal pigment. The green of a tree-frog or lizard has a similar origin. Living cells near the skin surface contain yellow oily droplets; beneath them are cells containing tiny granules that scatter green light more than yellow or red, which are absorbed by black cells beneath those containing the granules. The species in figure 13 was named *coerulea* from a specimen which was blueish as a result of being preserved in alcohol; this coloration resulted because the yellow pigment is soluble in alcohol, and without it blue as well as green rays of light penetrate to the cells containing granules; the latter scatter blue light in

addition to green. Proof that such blues and greens are structural colours is that when a blue or green feather is viewed by transmitted light its colour vanishes, whereas the colours of red and yellow feathers remain.

Another sort of structural coloration is to be seen in the cock's iridescent feathers, and more brilliantly in the moth of figure 5. Unlike the blues and greens just described, these colours change in hue according to the angle from which they are seen. The cause is the same as that of colours seen in soap bubbles or in films of oil on water, namely destructive interference of monochromatic components of white light reflected from two superimposed surfaces, the particular wavelengths eliminated depending upon the angle of incidence and the distance between the surfaces. In a fly's wings the iridescent colours are due to transparent layers of cuticle having different refractive indices. The brilliant colours of some beetles (figure 1) and of peacocks' feathers (figure 2) have a similar cause, and so too have the iridescent chaetae of the sea-mouse (figure 3) and the mother-of-pearl of shells (figure 4). In the moth of figure 5, and in many butterflies, the surfaces responsible for interference are layers of the transparent wing scales, and the colours instantaneously disappear when a drop of ether is put on the wing and fills the air spaces between the scales; as the ether evaporates, the colours return.

Thus the structural colours of animals may be caused by Tyndall scattering or by interference resulting from reflection from superimposed layers. In inanimate objects additional causes of non-pigmentary colours include diffraction from a grating and selective reflection from a metallic surface. Among animals, however, diffraction colours are rare, being found in a very few beetles, and selective reflection is unknown.

Whiteness can be due either to the reflection of all visible light by an opaque object of a specific chemical composition, e.g. calcium carbonate of a shell, or to reflection from numerous surfaces of a transparent substance, irrespective of its chemical composition, e.g. foam or snow. The latter phenomenon is the cause of whiteness in butterflies, which have ribbed scales, some with air-filled cavities; and of whiteness in feathers (figure 14) or hair, which have internal air-bubbles. Blackness is caused by total absorption of light; in animals this is usually due to a black pigment called melanin, seen in the salamander (figure 9), the crow, a black cat, dark human skin, and the ink squirted in defence by the octopus. It is melanin that absorbs the long-wave light in blue and green feathers, and in the green frog's skin. Melanin is insoluble and its chemical composition is not fully known, but the steps in its synthesis are partly understood. The amino-acid tyrosine, with the help of an enzyme containing copper, is oxidized by oxygen to a red indole derivative, which is then polymerized to give black melanin. Albino mammals and birds lack the enzyme, while piebalds have it in their black parts only. Light sometimes plays a part in melanin formation, as we know from the development of sunburn; thus, many animals are darker on the upper side, and if flounders are illuminated from below, they develop melanin on the underside. But the negro's skin needs no light to produce melanin, nor do frog's eggs within the body, nor octopus ink. Melanin is not always black: the yellow colour of the hair of blondes and of cats (figure 7) is said to be due to melanin. The nature of the colour of red hair, however, in redheads or chestnut horses, is not yet understood.

There is a second cause of blackness in animals, only recently explained [2]. A beetle is black because a phenol, with the help of an enzyme, becomes oxidized by oxygen to a quinone; the quinone then tans a protein in the cuticle by linking adjacent polypeptide chains, so making the protein insoluble and hard, and incidentally blackening it. This tanning process is now known to be frequent in invertebrate cuticles.

Melanin is synthesized by animals themselves, but there is a very widespread type of pigment which animals seem unable to make themselves and is derived from plant food. This derivation is apparent in the colour of egg yolk or butter, which varies with the animal's diet. These pigments were formerly called lipochromes because they are soluble in fat and fat-solvents; they are now known as carotenoids, since they have been shown to be related to the colouring matter of the carrot. Carotenoids, of which the best known are carotene and xanthophyll, are widespread in plants: many yellow flowers, and fruits such as the tomato, are coloured by them; they are present also in the green parts, where they are normally concealed by chlorophyll but are visible, for example, in ripe corn. The carotenoids can be separated by utilizing their differing solubilities and by chromatography: subsequent spectroscopy can confirm identification. Chemically, the molecule consists of a long, conjugated hydrocarbon chain terminating at each end in a ring [3]. Most of the yellows and reds of feathers, and of yellow

beaks (figure 10), are due to carotenoids, and so is the outer yellow layer involved in the green coloration of feathers and of frog's skin. The goldfish's skin and the newt's belly are pigmented by orange carotenoids, while salmon muscle and flamingos' feathers (figure 14) are coloured by a pink variety. Very frequently carotenoids in animals are united with proteins. These carotenoid-proteins are soluble in water and have many colours. The lobster's blue shell and red antennae (figure 6), for instance, and the green and orange of shore crabs (figure 12), are due to carotenoid-proteins. The bright red colour which appears when a lobster or crab is cooked is that of a carotenoid, a derivative of astaxanthene, which has separated from its protein after the latter has been coagulated by heat. There is even a colourless carotenoid-protein: a living prawn has a colourless shell and skin, but after boiling these structures become pink, as in the lobster.

All carotenoids of animals seem to be derived ultimately from plant food, and not to be synthesized by the animals. Astaxanthene, however, is rarely found in plants and must be formed in crustaceans from a plant carotenoid. Animals often get their carotenoids indirectly from plants by eating herbivorous prey. The red skin-spots, and occasional pink muscle, of trout are due to astaxanthene. Feeding captive trout with freshwater shrimps maintains the colours, but they are lost on a diet of butcher's meat [4]; the shrimps had made their astaxanthene from a plant carotenoid. The feathers of flamingos in captivity, when renewed after a moult, are no longer pink unless shrimps have been given with the food; the shrimps got their carotenoids from algae. The red colour of the sea-anemone in figure 11 is due to a carotenoid-protein; amputated tentacles of the anemone are replaced, and if shrimp is given as food the new tentacles become red, but with colourless fish as food they too are colourless [5].

Gowland Hopkins, sixty-five years ago, found in butterflies' wings substances which are allied to uric acid. Since then these compounds, now known as pterins, have been found to be widespread as animal colouring matters. Yellow xanthopterin is seen in pierid butterflies (figure 8), in wasps, and in the salamander (figure 9) [6]. Red erythropterin colours the wings of various butterflies and causes the red markings on the common frog [6]. Some pterins fluoresce in ultra-violet light, and it is well worth while looking at a butterfly collection illuminated by a lamp giving out ultra-violet but little or no visible light. The white or silvery aspect of the underside of fishes is due to the reflection of white light by microcrystalline guanine, also related to uric acid.

Quite a different chemical substance is responsible for the reddish colour of the sea-urchin's shell (figure 18). This pigment is called echinochrome; chemically it is a quinone of naphthalene, a compound with two condensed benzene rings. Echinochrome has been found in no other kind of animal, but from a plant is obtained another naphthaquinone, from which the dyestuff henna is prepared. However, a relation of the sea-urchin, a sea-lily or crinoid, living in the Jurassic sea 150 million years ago, was coloured by a violet quinone pigment having a number of condensed benzene rings; this has remained crystallized until this day [7]. The only other similar animal pigment known is the red colouring matter in the fat-body of the cochineal scale insect. Carmine is prepared from it; it is an anthraquinone, with three condensed benzene rings.

We come now to one of the best-known animal pigments, namely haemoglobin [8]. This colouring matter of our blood and of red meat is seldom responsible for the general body-colour of animals, but we ourselves, earthworms, water-fleas, and some other crustaceans (figure 16) are coloured by haemoglobin. The molecule consists of a red-coloured part, haem, united to a colourless protein. Haem is composed of four pyrroles attached together by four methene bridges to form a ring, in the middle of which is an iron atom linked to the four pyrrole nitrogens. When the iron is removed we are left with protoporphyrin. Another variety of porphyrin, with a copper atom in place of the iron of haem, is a unique red pigment which colours wing-feathers in the African touraco bird (figure 17). This pigment, turacin [9], is very soluble in weak alkali and rapidly leaches out of feathers immersed in such a solution. Turacin has two strong absorption bands, which are easily seen by looking through a feather at a light with a hand spectroscope.

The haem of our blood is continuously being broken down to bile pigment, which is excreted. This pigment is formed from the porphyrin by the oxidative breakage of one methene bridge. There are various varieties of bile pigment, with different colours, which depend on their state of oxidation. One variety colours some birds' eggs blue, and another makes the bones of the garfish green.

There are many green insects, such as caterpillars, grasshoppers, and the well known leaf-insect.

FIGURE 1 – *Beetles with structural coloration.*

FIGURE 2 – *Peacock's feather.*

FIGURE 3 – *Sea-mouse,* Aphrodite aculeata.

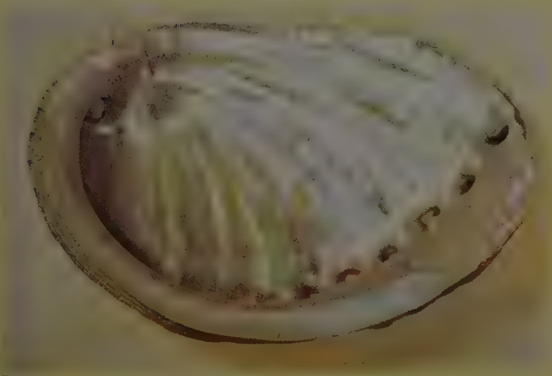

FIGURE 4 – *Ormer,* Haliotis tuberculata.

FIGURE 5 – *Day-flying moth,* Urania rhiphoeus, *from Madagascar.*

FIGURE 6 – *Lobster.*

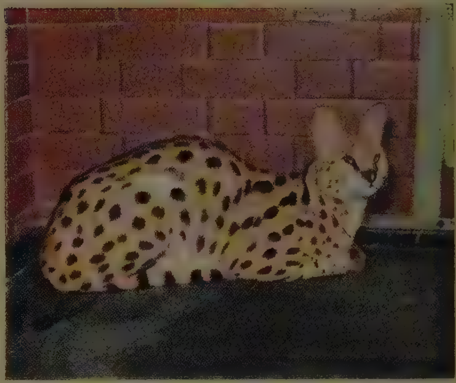

FIGURE 7 – *Serval, from Africa.*

FIGURE 8 – *Brimstone and clouded yellow butterflies.*

FIGURE 9 – *European salamander.*

FIGURE 10 – *Yellow-naped great barbet, from the Himalayas.*

FIGURE 11 – *Sea-anemone,* Actinia equina, *with its reflection.*

FIGURE 12 – *Shore crabs,* Carcinus maenas.

FIGURE 13 – *Australian tree-frog,* Hyla coerulea.

FIGURE 14 – *Flamingos.*

Figures 7, 10, 11, 13, and 14 were made from photographs taken at the London Zoo.

FIGURE 16 (*above*) – *Apus*, Triops cancriformis, *from Hampshire*. (Natural size)

FIGURE 15 (*left*) – *Quins*, Pecten opercularis.

FIGURE 17 – *Feathers of a touraco.*

FIGURE 18 – *Test of sea-urchin*, Echinus esculentus, *lit from within.*

It was once thought that this green colour is derived from chlorophyll in their food, but it is now known that the insects' green colour results from a mixture of a yellow with a blue pigment in the blood or skin. Such a mixture of pigments is green because the yellow pigment absorbs blue and violet, while the blue one absorbs red and yellow, but both reflect green. The insect's blue is a bile pigment and its yellow a carotenoid, both combined with proteins [10].

To summarize: blue is a structural colour in feathers, insects, and our eyes, but is due to a carotenoid-protein pigment in the lobster and to a bile pigment in some birds' eggs. Green is structural in beetles and the moth *Urania*, and partly so in feathers and frogs; it is a carotenoid-protein in crabs and a mixture of such with a bile pigment in insects. Yellow is due to a carotenoid in feathers, a melanin in hair, and a pterin in the salamander and butterflies. Red is structural in beetles; a carotenoid in sea-anemones, crabs, trout, and flamingos; a pterin in butterflies and the common frog; and it is due to echinochrome in the sea-urchin, to haemoglobin in ourselves and worms, and to a copper-porphyrin in touraco feathers. Black is caused by melanin in skin, hair, and feathers, and by a tanned protein in beetles. There remain, however, a number of animal colouring matters whose chemical nature and physiological origin are still unknown: an example of these is the beautiful coloration of the scallops seen in figure 15 and of many other shells.

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Book reviews

THE SOLAR SYSTEM

On the Origin of the Solar System, *by H. Alfvén. Pp.* viii + 194. *The Clarendon Press, Oxford.* 1954. 30*s. net.*

The theory of the origin of the solar system which is developed by Professor Alfvén in this book supposes that the planets were formed by electromagnetic action from a gas cloud surrounding the Sun, possibly the cloud from which the Sun had itself condensed. It is assumed that at that time the Sun possessed a general magnetic field; under the action of gravitation the ionized gas tended to fall towards the Sun, but the magnetic field tended to impede the fall. The elements with the highest ionization potentials became de-ionized first. As de-ionization proceeded, the non-ionized components diffused through those still ionized. Reasons are given for supposing that three, or possibly four, non-ionized clouds, differing in chemical composition, were formed, which successively fell towards the Sun.

It is supposed that in falling towards the Sun these gaseous clouds interacted in such a way that their kinetic energy was transformed into heat. Thermal ionization ensued, and when it had reached a certain limit the cloud was stopped. Angular momentum was then transferred to it from the central body, resulting in a concentration of the gas towards the equatorial plane.

The mechanism of the process by which the falling of the clouds towards the Sun was stopped is not at all clear; this is the weak point of the theory, which is entirely dependent upon its validity. If this point could be more fully substantiated, the theory would command a much wider acceptance, for it achieves a considerable measure of success in accounting not only for the main features of the planetary system but for those of the satellite systems, providing that each of the planets had a magnetic field above a certain value. The book is an important contribution to the literature on the origin of the solar system and is deserving of serious study.

H. SPENCER JONES

INTERSTELLAR MATTER

Nébuleuses Galactiques et Matière Interstellaire, *by Jean Dufay. Pp.* 492. *Éditions Albin Michel, Paris.* 1954. *Fcs.* 1650 *net.*

The study of interstellar matter, which consists partly of gas of extremely low density and partly of small solid particles, has become of great importance in astrophysics. This matter is revealed in various ways, by the bright gaseous nebulae made luminous by the stars embedded in them; by the obscuring clouds of dust, which dim or completely obscure the stars behind them; by selective absorption and scattering of the light of the stars, causing dimming and reddening; by the stationary lines in the spectra of distant stars.

An extensive and rapidly growing literature is concerned with the observations of these phenomena, their analysis, discussion, and interpretation. Physical theories differing widely in their nature and scope are involved in such problems, for instance, as the interpretation of the 'forbidden' lines

in nebular spectra and the conclusions that can be drawn from the investigations of selective absorption about the size and nature of dust particles.

The interstellar matter is strongly condensed towards the central planes of the Milky Way and of the external galaxies. It is present in the spiral arms but not in the central nuclei. The formation of stars from this matter is still taking place, through its condensation first into grains and then gradually into larger masses.

This book by M. Dufay provides the most complete account available of the many diverse phenomena, observational and theoretical, involved in the study of the interstellar matter. It is not overloaded with mathematics, but the general principles of mathematical investigations are adequately described. The very full bibliography is useful for reference purposes. A detailed index would have added to the value of the book, but the omission of an index is not uncommon in French textbooks. The selection of plates, all from photographs taken at the observatories of Forcalquier or Haute-Provence, is good, and the reproductions are excellent.

H. SPENCER JONES

ISOTOPES AS TRACERS

Isotopic Tracers, *by G. E. Francis, W. Mulligan, and A. Wormall. Pp. xvi +* 386. *University of London, The Athlone Press, London.* 1954. 37*s.* 6*d. net.*

This book is an elementary introduction to the principles and practice of isotope tracing in biological chemistry, with particular reference to medical research. As such it is an excellent book, readable and lucid. It fulfils a real need of the student or research worker with biological training and interests who, though faced with a problem suitable for tracer technique, is naturally reluctant to embark upon methods largely based on recent research in nuclear physics. This need has been ignored by some earlier writers who have erred, perhaps, on the formal side in their treatment of the basic physics. Professor Wormall and his colleagues have clearly been inspired by a sympathy for the biological reader and by their first-hand experience in biochemical tracing.

The title of the book might usefully have been more specific. For example, there is scarcely any mention of the important and elegant applications of isotope tracers in physical chemistry and in agriculture. The larger section of the book (pp. 1–214) describes the principles of the preparation, and the properties, of radioactive and stable isotopes. There is practical discussion of the methods of isotope assay and of their safe manipulation in the laboratory. A synopsis of illustrative tracer experiments, drawn almost exclusively from the field of vertebrate metabolism, concludes this section.

The final section of the book consists of a simple practical course for students, and includes some novel exercises with serum proteins labelled with iodine-131. There are useful appendices relating to the supply and assay of radioactive isotopes. The book can be highly recommended as a practical introduction to the subject for teachers and students of biochemistry or physiology.

F. P. W. WINTERINGHAM

GENERAL BIOLOGY

Biologia Generale, *by E. Pàdoa. Pp.* 707. *Edizioni Scientifiche Einaudi, Turin.* 1953. *L.* 8000 *net.*

This textbook of general biology is primarily intended for medical students in their first year; it is, however, a source of general, up to date and critical information and is suitable for providing the general practitioner with a biological background. It is, in fact, so readable and clear that it can be recommended as a source of detailed information to those who, although not specifically trained in biology, wish to acquire knowledge in this field.

The first part is devoted to a very satisfactory account of the structure, fine structure, chemical composition, and metabolic activities of living organisms. In particular, present knowledge of the fine structures of protoplasm and their physiological significance is summarized in a convincing way. The chapters which follow deal with reproduction, embryology, and growth; the account of the latter is up to date, and the numerous data presented are linked together critically.

The chapters on genetics, evolution, and classification are relatively long, and the various subjects are expounded penetratingly and make the reader acquainted not only with existing knowledge, but also with many contemporary arguments on a number of problems. The same is true of the last chapter, on ecology, which is very interesting from a general viewpoint.

The book contains an adequate bibliography covering the period up to 1953. It is well produced and, on the whole, is one of the best Italian books on biological science published in the last two years.

M. ALOISI

GENETICS

The Biochemistry of Genetics, *by J. B. S. Haldane. Pp.* 144. *George Allen and Unwin Limited, London.* 1954. 15*s. net.*

When it was pointed out that Mendelian segregation concerned chemical differences between organisms, the foundation of a new and very exact science was laid. That happened in 1902. But only within the last twenty years has a solid structure of knowledge come into being to which we may give the name of biochemical genetics. The new science has arisen by a combination of radically different techniques and systems of inference. The important combination has been between the chemistry of genes in the cell and the chemistry of their actions, first in very large organisms and later (with quite different consequences) in very small organisms.

In the present book Professor Haldane discusses these great developments in their various aspects. He writes for biochemists, but geneticists will be equally interested. In detail he is successful, but this is a subject of varied technicality; it demands concentrated thought in the reader. It therefore needs to be presented with conviction and coherence and without affectation. Haldane's treatment is unfortunately disconnected: the essential unity is lacking. It is also interrupted by a political and personal cross-fire which distracts and discourages the serious reader, and shatters what we must suppose is the author's serious intention. Undoubtedly the result is a valuable book, but it misses being a good book.

C. D. DARLINGTON

PROTEIN STRUCTURE

The Chemical Structure of Proteins, *edited by G. E. W. Wolstenholme and Margaret P. Cameron. Pp.* 222, *with half-tone and line illustrations. Ciba Foundation Symposium. J. and A. Churchill Limited, London,* 1953. 25*s. net.*

During the last few years the most important advances in our knowledge of the structure of proteins have been derived from the application of chemical analytical tools of great refinement. Following a stage where the main

endeavour was to develop methods of amino-acid analysis sufficiently precise to indicate exactly the number of residues of each type present in the molecule, recent work has concentrated on ways of establishing the order of these residues along the polypeptide chains. The Ciba Foundation performed a valuable service by making it possible for the world's leading workers in this field to meet in December 1952; the volume under review, which contains the papers presented to this conference together with verbatim reports of the discussions, is to be commended as a vivid and comprehensive, yet concise, account of the status of this important and rapidly-growing subject.

The topics discussed include new protein fractionation procedures of high resolution (Craig, Stein, Porter); end-group determination (Desnuelle, Chibnall, Fromageot); chemical step-by-step degradation of polypeptide chains (Edman, Fraenkel-Conrat, D. F. Elliott, Turba, Wieland); enzymatic degradation methods (E. L. Smith); and finally studies of a number of particular substances (Synge, Felix, Boulanger, Schroeder, Grassmann). To summarize, it may be said that we now have at our disposal a number of elegant methods which in principle might solve many, or even all, problems connected with the amino-acid sequence of proteins. In fact their applications have as yet been restricted, except in a few favourable cases, but this is a situation which is rapidly changing.

J. C. KENDREW

CHEMICAL CONSTITUTION

Chemical Constitution, *by J. A. A. Ketelaar. Pp. viii + 398. Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London.* 1953. 40*s. net.*

This very interesting book deals with the physical principles underlying our present conceptions of interatomic and intermolecular forces, illustrated by a wide variety of examples from both inorganic and organic chemistry. Quite rightly, though somewhat uncommonly, the author considers the phenomena of chemistry as a unified whole. The properties of substances are discussed and compared against the background of four types of bonding—the ionic bond, the atomic bond, the covalent bond, and van der Waals bonding. In the first category there is a wealth of data on complexes and intermolecular compounds of different sorts, and the properties of some of these substances are correlated with crystal structure. There is a clear exposition of the wave-mechanical principles of covalency, of bond energies, and of resonance; the valency bond and molecular orbital methods for treating molecular electronic configurations are surveyed critically. The reader will welcome the clear account of such topics as directed valency, multiple bond character, conjugation, and colour in terms of modern valency theory. The chapter on the metallic bond includes a simplified but instructive account of the electron theory of metals, Brillouin zones, and the properties of alloys. That on van der Waals interactions contains much of current interest on molecular compound formation and the physical properties associated with it.

This book displays a refreshing approach to the more interesting topics of chemistry and should prove stimulating not only to student readers but to others who wish to review the advancing front of chemical theory.

H. W. THOMPSON

CATALYSIS

Catalysis, Volume I: Fundamental Principles (Part 1), *edited by Paul H. Emmett. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 80*s. net.*

This is the first of several volumes planned to show the present state of knowledge, both theoretical and practical, of catalysis. Of the eight chapters, two deal with practical methods for preparing catalysts, and with supports and promoters. A chapter on magnetism and catalysis describes methods for investigating magnetic properties, but, beyond an initial statement that many elements of major importance in catalysis show 'interesting magnetic properties,' does little to establish this connection and nothing to reveal its cause if it exists. Other chapters deal with physical adsorption and with the measurement of surface area; the latter is competent and critical with special emphasis on the *BET* method, which assumes a complete monolayer when the adsorption isotherm for gases shows a rather sudden change of direction.

The most coherent section of the book contains three chapters by Laidler, on chemisorption, on kinetic laws in surface chemistry, and on the theory of absolute reaction rates in surface reactions. The first two contain plenty of up to date experimental material; in the third the properties assumed for the surfaces are largely hypothetical, and quantitative application to actual cases is scarcely possible yet. Homogeneous catalysis is reserved for a later volume.

While very useful, this volume is in one respect disappointing; there is no serious attempt to explain why surface catalysts work, why reactions occur on them which cannot otherwise take place. Very little attention is paid to the question of how far catalytic power depends on the geometrical spacing of the surface atoms. Such a connection was suggested long ago, is intrinsically very probable, and has received much support from the work of the late Otto Beeck. None of the authors seem to realize that straining of the adsorbed molecules through lack of correspondence between the normal distance between their atoms, and the distance between the surface atoms to which they are bound, is a very likely cause for their enhanced reactivity. May we hope that this fundamental question will be properly discussed in a later volume?

N. K. ADAM

FRENCH-ENGLISH DICTIONARY

A French-English Dictionary for Chemists (*2nd edition*), *by Austin M. Patterson. Pp. xiv + 476. Chapman and Hall Limited, London.* 1954. 52*s. net.*

The appearance of a second edition of this dictionary will be generally welcomed, for since it was first published in 1921 it has become an accepted work of reference. However, the advance of chemistry has been so rapid in the last quarter of a century, and so many completely new fields have been opened up, that inevitably many new terms have come into general use, while others have become obsolete. In the new edition the vocabulary has been increased to 42 000 terms, compared with 35 000 in the original; random sampling in search of modern terms indicated that the revision has been satisfactorily done.

TREVOR I. WILLIAMS

FORMALDEHYDE

Formaldehyde (*2nd edition*), *by J. F. Walker. Pp. 575. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 96*s. net.*

The first edition of this book on formaldehyde was published in 1944, and it has now been completely revised. It

is comprehensive and covers ground of interest both to the pure scientist and to the manufacturer and user of formaldehyde. The chapters include ones on formaldehyde production; monomeric formaldehyde; state of dissolved formaldehyde; commercial formaldehyde solutions; physical properties of aqueous formaldehyde; distillation of formaldehyde solutions; formaldehyde polymers; chemical properties of formaldehyde; the reactions of formaldehyde with inorganic reagents, aliphatic hydroxy compounds and mercaptans, aldehydes and ketones, phenols, carboxylic acids, acid anhydrides, ketene, acid chlorides and esters, amines, amides, nitriles, hydrocarbons and hydrocarbon derivatives, and with heterocyclic compounds; detection and estimation of formaldehyde, quantitative analysis of formaldehyde solutions and polymers; hexamethylenetetramine; uses of formaldehyde, formaldehyde polymers, and hexamethylenetetramine.

This is a fascinating and stimulating book throughout. The coverage is excellent, and the reviewer has noted the absence of only one reaction of formaldehyde—its use in detecting traces of aromatic hydrocarbons by Ramsden's method. Bibliographies are given in each chapter, the total number of references being well over 2000. Printing and formulae are of the highest standard. The only errors detected are on pp. 332 and 361; in view of the evidence cited there seems no grounds for regarding the structure of hexamethylenetetramine as being in doubt (p. 404). There are author and subject indexes.

W. BAKER

FURANS

The Furans, *by A. P. Dunlop and F. N. Peters. Pp.* 867. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1953. 144*s. net.*

This substantial volume on the furans, from the laboratories of The Quaker Oats Company, deals comprehensively with the literature and applications of these substances up to the end of 1950. Part I (700 pages) reviews the chemistry of the furans; Part II (100 pages) reviews the industrial applications of furfural and its derivatives. An appendix lists the patents on furan resins; there is a full subject index, but no author index.

The chapters in Part I are on the physical characteristics of the furans; furan and its homologues; halogen derivatives; nitro compounds, furanols and furylamines; metallic compounds; furfuryl alcohol and other furan alcohols; furfural and other fural aldehydes and ketones; furan carboxylic acids; cleavage of the furan nucleus; and catalytic reduction of furans. Benzofurans are not included.

This book contains a wealth of information and will be an indispensable reference book on furan chemistry. The field is thoroughly covered, and the frequent use of tables facilitates rapid search for particular compounds and examples of reaction types. Each chapter contains generous references to modern chemical literature; the book contains well over 5000 such references. The type and formulae are throughout excellent, and it is attractive to find that electronic mechanisms are discussed in connection with certain reactions.

W. BAKER

ORGANIC CHEMISTRY

Lehrbuch der Organischen Chemie (12*th edition*), *by P. Karrer. Pp. xx* + 949. *Georg Thieme Verlag, Suttgart.* 1954. *DM* 59.70 *net.*

Once again Professor Karrer has revised his famous textbook and brought it completely up to date. The arrangement of subject matter follows that of the previous editions, and is based in a systematic way on the nature and number of functional groups in aliphatic, in alicyclic, and in heterocyclic compounds. Many parts of the text have undergone extensive revision, and the extra space devoted to certain topics, in particular reaction mechanisms, has entailed abbreviation in other places and the omission of the majority of the tables.

Recently developed reagents, e.g. $LiAlH_4$, are mentioned frequently; new compounds of biochemical interest, e.g. the S-acetyl derivative of coenzyme A, are discussed; and even the very recently determined structures of terramycin and aureomycin are given. Tropolones are accorded three pages, and the use of inclusion compounds of urea and of tri-*o*-thymotide for the resolution of enantiomorphous compounds is briefly mentioned. In brief, it may be said that no significant advance in organic chemistry made since the last edition has been omitted.

Karrer's book is probably the best available single-volume textbook of organic chemistry for students and research workers, and for reference purposes, and can be recommended most highly.

J. F. W. MCOMIE

HISTORY OF TECHNOLOGY

A History of Technology, *edited by Charles Singer, E. J. Holmyard, and A. R. Hall.* (*Volume* 1. *From early times to the fall of the ancient empires.*) *Pp. lxiv* + 827, *with numerous illustrations. Clarendon Press, Oxford.* £7 7*s. net.*

Some 900 pages have gone to the making of this volume, yet it is only the first of five which have been planned and already more than half completed in print or typescript. So massive a work implies endowment, and in fact the liberal benefactor is Imperial Chemical Industries Limited. But neither size nor patronage, impressive though both be, can be described as primary aspects of this ambitious scheme. The significant factor is the increasingly dominant position of technology and the technician in modern life, with the reflection of that trend in modern historical or archaeological studies as an inevitable corollary. 'How things are done and made' is the preface to 'Why they are made' and to 'What are the consequences of their making.' In other words, a causative sequence based on technology has become in a considerable measure the backbone of history, in the widest sense of the term. This great miscellany therefore fits aptly into the modern milieu, and indeed must represent for some time to come a standard work of reference for historian and archaeologist alike.

This first volume deals with preclassical times, and ranges in subject-matter from a biological account of skill as a human possession to detailed studies such as those of speech, calculation, writing, building, transport, lighting, agriculture, and astronomy. The thirty-one sections on these and other topics are contributed by recognized experts and are admirably illustrated by plates and careful line drawings. For all its wide extent and miscellaneous character the book is a great deal more than a mere encyclopaedia. Many of the individual articles are creative work and represent substantive additions to knowledge. At the same time, they are almost uniformly written in clear, sensible language intelligible to the unspecialized reader. For watchfulness in this matter, as for the sound organic planning of the work as a whole, high credit is due to the veteran historian of science, Dr Charles Singer, and to his editorial colleagues, Dr E. J. Holmyard and Dr A. R. Hall.

The price is high. Whether read as a discontinuous story of human achievement or referred to intermittently on

specific points, the volume would have been more manageable had it been bound in two separate parts, with the further advantage that parts sold separately would have constituted a less terrifying impact upon the purse. This criticism apart, the Clarendon Press has produced a nearly faultless library-book. If in the fullness of time a very much smaller and cheaper compendium, approximating perhaps to a dictionary, could be extracted from it, more modest shelves would greatly benefit. Meanwhile let us salute a redoubtable band of scholars and a munificent patron. R. E. M. WHEELER

EXPERIMENTAL INORGANIC CHEMISTRY

Experimental Inorganic Chemistry, *by W. G. Palmer. Pp. xx + 578. Cambridge University Press, London.* 1954. 50*s. net.*

Dr Palmer propounds the question: 'Since organic chemistry is taught mainly through the laboratory, should not inorganic chemistry be taught in the same way?' He believes that it should, and that the methods now usually followed are uninspiring and productive of boredom. Many will agree with him that the qualitative analysis of artificially compounded mixtures, and the arteriosclerotic selections of quantitative analyses, which go to form the elementary student's exercises in practical inorganic chemistry, are unlikely to stimulate the enthusiasm so generally shown for practical organic work. One of the difficulties of making an effective change is the lack of suitable textbooks, so, with commendable energy and resolution, Dr Palmer undertook the very considerable labour of writing a book in which his conceptions of how inorganic chemistry should be taught in the laboratory find practical expression. It must be said at once that he has been most successful, and it will not be surprising if the book rejuvenates the relevant part of the chemical curriculum.

After a general theoretical introduction, dealing with such topics as atomic structure, chemical linkage, interatomic separations, metallic elements, electrochemical processes, and crystal structure and habit, Dr Palmer has arranged his course in order of the groups of the periodic system (excluding group O). Each section has an introduction, followed by careful and well-tested instructions for preparative work, and many of the preparations are complemented by directions for analysis of the products, an excellent idea inasmuch as the student is likely to enjoy analysing substances he has himself prepared. The preparations vary in difficulty, but the selection is wide and very interesting. E. J. HOLMYARD

MOLECULAR STRUCTURE

Organic Crystals and Molecules, *by J. Monteath Robertson. Pp.* 340. *Cornell University Press, Ithaca, New York.* 1953. 32*s.* 6*d. net.*

Even the original audience may benefit from the printed copy of a visiting lecturer's spoken word. What song the Sirens sang is a puzzling question, but not beyond all conjecture, yet who shall say what meaning the bell-like tones of Glasgow had in the ears of Ithaca? Lecturers have no closely defined textbook limits, and Professor Robertson, visiting Cornell, talked without encyclopaedic intent of the things he likes.

Early successes of X-ray diffraction were in inorganic chemistry. In organic chemistry only a few simple organic molecules could then be examined, but in the last twenty years alkaloids and steroids have been measured and their molecular forms revealed in a manner more complete, more quantitative, than classical methods could achieve. Ahead appears the possibility of surveying the most complex products of nature and of the laboratory. Methods which make this possible and difficulties which retard development are here described. Part I deals with technique and principles of interpretation; part II is descriptive and starts with fundamental structures, diamond, graphite, urea, hexamethylbenzene, and others which reveal basic structural arrangements in organic molecules. There follows a study of measurements of condensed-ring hydrocarbons, leading to discussion of the general relationship between bond-length and bond-character. Another chapter deals with complex and partially known chemical structures. How organic molecules build the whole crystal is considered, but emphasis is mainly on the forms of molecules.

Some parts an organic chemist might skip, omission of a favourite molecule he may regret; but there is nothing he should not enjoy. H. M. POWELL

NEWTON

Sir Isaac Newton, *by E. N. da C. Andrade. Pp.* 140. *Collins, London.* 1954. 7*s.* 6*d. net.*

Newton was the greatest of all men of science. The standard biography was for long that published in 1855 by Sir David Bewster: it had the defect that Newton was presented as without faults of any kind, and it was superseded in 1934 by the more balanced judgment of L. T. More. The present "Brief Life" is slight compared with More, but Professor Andrade is perhaps the best living authority on the subject, and it is supremely well done. There is a brilliant account of Newton's discoveries, and at the same time a sympathetic understanding of his psychology, the great misfortune in which was a morbid fear of opposition from others. This was the source of his troubles with Hooke concerning optics, with Leibnitz on the discovery of the calculus, and with Flamsteed on astronomy. Much of the work that first appeared in 1704 in his *Opticks* had been discovered much earlier, but he would not publish it so long as Hooke lived. His law of gravitation, and the theory of the motion of the heavenly bodies based on it, might have remained his own secret if Halley and the Royal Society had not used the utmost force they could command.

E. T. WHITTAKER

THE CULTURE OF CHINA

Science and Civilisation in China, *by Joseph Needham, with the research assistance of Wang Ling. Vol. I. Pp. xxxviii +* 318. *Cambridge University Press.* 1954. 52*s.* 6*d. net.*

Historians of science have long bemoaned the fact that there is no even remotely adequate account of the development of science and technology in ancient and medieval China. Travellers' tales throughout the centuries have indeed ascribed numerous inventions and discoveries to the Chinese, and sufficient more trustworthy information was available to make it seem likely that Chinese craftsmen, physicians, alchemists, astronomers, and engineers were as accomplished as their Western counterparts, at least until the last three or four hundred years. There has, however, so far been no authoritative work on the subject, and it is therefore a matter of congratulation that Dr Needham has courageously attacked the problems with which it bristles. He is uniquely equipped for the task: an eminent scientist, a practical writer on the history of science, and a sinologist with a knowledge of the language and the

people, he has the full armoury not only desirable but requisite. The complete work, of which this is the first instalment, will be in seven volumes, and the six still to be published are already completed in manuscript. Volume I serves as an introduction to the whole; in it Dr Needham discusses the Chinese language, Chinese geography and history, and the scientific contacts between China, the Middle East, and Europe during the period under review. Even by itself this book is a most valuable contribution to the study of an obscure region of the history of science; as a prelude to the more detailed studies to come it will whet the appetites of all who read it. Finely conceived, written, and produced, and fully documented, it is a book to be read by everyone interested in the development of science and civilization. The Cambridge University Press deserves our thanks for publishing so handsome and important a work at such a modest price. E. J. HOLMYARD

CURRENCY OF CIVILIZATION

The Hand Produced Book, *by David Diringer. Pp.* 604. *Hutchinson's Scientific and Technical Publications, London.* 1953. 60*s. net.*

As a title, 'The Hand Produced Book' no more does justice to the scope of this work than 'The Alphabet' did to its predecessor; both deal with parts of one subject, the transmission of thought. In his earlier book Dr Diringer wrote of the development of techniques for recording thought: here he describes an equally important development, that in which the record was made permanent and portable.

This book is indeed, much more an account of a phase in the civilizing process than a history of any one identifiable object. To the European bibliophile the 'hand produced book' suggests perhaps the ninth-century 'Book of Kells' or, at the most ancient, the fourth-century *Codex Sinaiticus.* Dr Diringer treats of these: but for his purpose the 'book' may be a Sumerian clay tablet of the third millenium B.C.; An Egyptian hieratic papyrus of the thirteenth century B.C.; a rune-carved stick from medieval Germany; or a Mayan deerskin written in the twelfth century A.D. in Yucatan. He has assembled, and presents briefly, authoritatively, and with ample illustration and indexing, the present state of knowledge on the materials, implements, and methods of book production, from prehistoric times to the invention of printing. He deals also with some of the historical forces which have impelled the multiplication of books.

The least satisfactory feature of this book is its plan. The earlier chapters trace the development of writing and the evolution of the book, from stick, stone, and leaf to clay tablet, papyrus, or leather scroll, and parchment codex. Then, after a chapter on Greek and Latin book production, another, entitled 'The book follows religion', traces the development of book production under Western and Eastern Christianity and the sects and religions of the Near and Middle East; it includes Jewish and Arabic literature. Two chapters then deal with 'outlying regions'—the rest of Asia and America. Finally, almost a fifth of the book is devoted to 'The Anglo-Celtic Contribution'. This chapter is an interesting and thorough monograph on Insular palaeography, but disproportionately long in a work covering the whole world, and one which cannot find space for equivalent treatment of post-Carolingian book production on the Continent. M. J. S. CLAPHAM

SCIENTIFIC THOUGHT

A History of the Sciences, *by S. F. Mason. Pp.* 520. *Routledge and Kegan Paul Limited, London.* 1953. 28*s. net.*

This new history of science is subtitled 'Main Currents of Scientific Thought', implying an emphasis on general trends and background rather than on the details of selected experimental and mathematical developments and applications. Thus there are no illustrations and few formulae.

The scope is extremely wide, and ranges from a neat summary of the sciences in the ancient civilizations and in the Far East to discussions of modern astrophysics and relativity theory. There are background chapters on medieval technology, scientific institutions, aspects of scientific nationalism, and other topics.

A theme that is developed through the work concerns 'the difference in outlook between the craft and scholarly traditions, which has existed throughout written history'. It is suggested, for instance, that the slow progress of Chinese science was influenced by the lack of contact between scholar, bureaucrat, and technician; and, in a modern context, the academic nature of Mendelian genetics is contrasted with the easier appeal to the agriculturalist of the Soviet theories of Michurin and Lysenko.

These 500 pages of close type do not make easy general reading. They form rather something in the nature of a first textbook to lead the student of the subject to further investigation, and to that end there is a good bibliography arranged under general and chapter headings.

Dr Mason's style is clear and concise. The twentieth-century scientist will particularly appreciate his grasp of modern as well as of ancient theory.

R. H. G. THOMSON

MINERALS FOR INDUSTRY

Minerals for the Chemical and Allied Industries, *by Sydney J. Johnstone. Pp.* 692. *Chapman and Hall Limited, London.* 1954. 75*s. net.*

This is a valuable and welcome addition to industrial chemical literature. Itself a mine of information, both qualitative and quantitative, it also contains, for each class of mineral described, extensive bibliographies and references to the relevant Standard Specifications. Post-war practice is fully dealt with, and the book is as up to date as is possible, due allowance being made for the time necessary to see it through the press. A list of some 160 firms and organizations from which the author has obtained information is an indication of the pains taken to secure thoroughly reliable material.

The section on lead illustrates the general treatment. It describes the chief ores; world production, listing the contributions of the principal producers; methods of smelting; the uses of lead, with details of the qualities used for various purposes in Britain, and standard tests prescribed for metal required for various purposes, e.g. chemical lead; and lead pigments.

Many minerals which have only comparatively recently assumed industrial importance—such as those of indium, thallium, uranium, vanadium, and zirconium—are comprehensively treated. All chemists seriously interested in chemical raw materials should have ready access to this book.

TREVOR I. WILLIAMS

INDUSTRIAL EXPERIMENTS

The Design and Analysis of Industrial Experiments, *edited by Owen L. Davies. Pp. xiv* + 637. *Oliver and Boyd Limited, Edinburgh* (*for Imperial Chemical Industries Limited*). 1954. 63*s. net.*

Many books on experimental design give full accounts of different designs but no guidance on how to choose one to suit a particular problem. Dr Davies and his colleagues not only provide an excellent textbook but offer invaluable advice on the circumstances in which various types of experiment are specially suitable; their argument is illustrated by discussion of over forty experiments in industrial chemistry. They give particular prominence to factorial designs, emphasizing their economy and the advantages of putting extra factors into an experiment. A short chapter on sequential experiments is a useful introduction to a rapidly developing field. Most interesting of all, perhaps, is the long, clear account of new techniques for estimating optimal conditions, for the development of which Dr Box, one of the authors, has been largely responsible.

Undoubtedly this book, the best yet published on statistical aspects of industrial experimentation, will help every industrial scientist. Statisticians also can learn from it a more realistic attitude to design, whether for industrial or for other research. The authors rightly insist first, that much quantitative research is inevitably statistical, and secondly, that 'a good experimental design is one which furnishes the required information with the minimum of experimental effort'. D. J. FINNEY

GENERAL PATHOLOGY

Lectures on General Pathology, *edited by Sir Howard Florey. Pp.* 733. *Lloyd-Luke (Medical Books) Limited, London.* 1954. 63*s. net.*

The twenty-seven lectures published in this book were written by ten masters of their subjects for students at Oxford who had already taken an honours degree in physiology and biochemistry, and who had therefore some experience of the experimental approach to biological problems. The course of lectures lasted for two terms. The writers are to be congratulated on their work, and so, incidentally, are the publishers for the way in which the text and the numerous illustrations have been produced.

The main lectures deal with general pathology — history, inflammation, fever, reactions of the blood to injury, antigens, and antibodies—and the pathogenicity and virulence of micro-organisms. There are lectures also on more biochemical aspects of the subject, such as haemorrhage, shock, and oedema, and two chapters on radiations. Some lectures will have more appeal than others, but it is almost unnecessary to say that as a whole they are stimulating and quite up to date in thought and outlook. Curiously enough, however, there are no lectures on tumours and their general effects upon the body, and a lecture on the pathology involved in deviations from the normal plane of nutrition would have been useful. Had these been included, however, we might have had to forgo Sir Howard Florey on the inflammation of mucous membranes and G. R. Cameron and E. P. Abraham on degenerative changes—which would have been very undesirable. Perhaps one day the syllabus will be extended to cover three terms.

Each lecture concludes with a list of original references, and there are both a subject and an author index in the book, the former useful but perhaps not sufficiently complete. The lectures will be appreciated by many more than those for whom they were written and delivered. R. A. McCANCE

METALS AND ALLOYS

The Structure of Metals and Alloys, *by William Hume-Rothery and G. V. Raynor. Pp. viii* + 363. *The Institute of Metals, London.* 1954. 35*s. net.*

The first edition of this book was written by Hume-Rothery in 1936, and reprints with revisions have appeared at regular intervals since then; this third edition, however, though conforming to the original scheme in many respects, is really a new book. The rapid development of that part of the science of metallurgy which depends upon a knowledge of atomic structures has demanded much fuller treatments of topics included in the first edition, and in addition there are new sections on ferrous alloys and on imperfections and dislocation theory. The process of enlargement has—perhaps inevitably in a rapidly developing subject—resulted in some change of emphasis; in particular, the book is no longer used to any serious extent for the exposition of original work, but is devoted almost entirely to the presentation of material already available in the literature.

The presentation is, of course, admirably clear. Technical crystallographic and mathematical notations are avoided, presumably on the assumption that these are not familiar to the student of metallurgy; but the physicist may be forgiven if he feels somewhat overwhelmed at the wealth of detailed information about alloy systems used in establishing and illustrating the principles involved. Two aspects of the authors' treatment, noted repeatedly, seem to the reviewer to be particularly fascinating—the skilful anticipation and overcoming of beginners' difficulties, and the glimpses afforded of the way in which the subject is developing when reasons are given for abandoning or modifying some of the ideas and suggestions advanced in the 1936 edition.

Production and printing are excellent (but what happened to figure 57 on page 71?), and the price is commendably low. W. H. TAYLOR

CHROMIUM AND ZIRCONIUM

Metallurgy of the Rarer Metals: No. 1—Chromium, *by A. H. Sully. Pp.* 272. No. 2—Zirconium, *by G. L. Miller. Pp.* 382. *Butterworths Scientific Publications, London.* 1954. 35*s. and* 45*s. respectively.*

These two volumes, which are the first of a series on some of the less common metals, appear at a time when the strategic importance of chromium and zirconium is rapidly increasing. In chromium metallurgy, the majority of recent developments have resulted from increases in purity, themselves resulting from the engineer's demand for materials with useful properties at elevated temperatures. In the case of zirconium, the rapid increases in production and in alloy research have been prompted by the excellent resistance to chemical attack that can be obtained, and the possible application of zirconium alloys in the atomic energy field. Each book is written by an authority on the metal concerned and both provide the prospective user with a wealth of information. They should stimulate the research worker to develop the basic knowledge of these metals still further. The field covered includes the occurrence, production, casting, fabrication, physical and chemical properties of the pure metals and their alloys, and existing constitutional data; full bibliographies are included. If the present standard is maintained, one can look forward with confidence to the subsequent volumes dealing with titanium, molybdenum, platinum, manganese, and uranium. B. W. MOTT

DEFORMATION ANALYSIS

Analysis of Deformation, *by K. Swainger. Volume* 1. *Pp. xix* + 285. *Chapman and Hall Limited, London.* 1954. 63*s. net.*

In this book a linear theory is formulated for analysing finite deformation in three dimensions. Three reference frames are used, as against one in classical elasticity. The author claims that his theory reveals deficiencies in the older theory, but this is open to doubt. The equations satisfied by the dilation v and the displacement U (11·15 and 11·19 on pp. 161–2) are not different from the classical equations when one considers the restriction (curl U = const) imposed by the author. But this restriction is untenable; for curl U is not constant in the Saint-Venant theory of torsion, nor in the case of flexure with shear. Moreover, the existence of a centre of flexure depends on curl U varying across a cross-section.

Vector analysis is used throughout the text, and with a view to making the book relatively self-contained there are appendices on vector analysis and potential theory. The book is well produced and the printing is clear, but it is a pity that ornate Old English characters have been used for some of the symbols. This gives to some pages, 117 for example, a bizarre appearance, and the author's unorthodox notation in places does not make for easy reading. When, for example, one sees an expression such as

$$S : P^n : \Delta S$$

after an integral sign, one has to search thoroughly to discover the meaning. The book is surely expensive, considering that it is but the first volume.

L. S. GODDARD

SEA FISH

The Sea Angler's Fishes, *by M. Kennedy. Pp.* 524. *Hutchinson's Scientific and Technical Publications, London.* 1954. 50*s. net.*

In many branches of science, theory and everyday practice are sharply separated. Nowhere, perhaps, is this divergence more marked than in marine zoology. By no means all ichthyologists, however profound their knowledge of structure and taxonomy, have the skill and experience necessary to angle successfully for fish; equally, anglers rarely have any detailed scientific knowledge of the fish they catch, although they may be adept at knowing where, when, and how to catch them. The publication of a comprehensive book on the fish which interest British sea anglers, written by a man who has a wide zoological knowledge of fish and is also a practised angler, is therefore noteworthy. Mr Kennedy shows considerable skill in uniting ichthyology and angling in a readable and well illustrated book. Accounts of anatomical details, feeding habits, spawning, and development of the fry are enlivened by recipes for cooking the fish when caught.

A preliminary chapter on the general biology of fishes introduces the technical terms necessary for furnishing clear information about the appearance and habits of the species later described, so that in the main text technicalities are kept to a minimum. From this book all sea anglers can gain an understanding of the principles which must guide successful fishing; its lesson for zoologists is that there is much that cannot be learnt in the laboratory.

TREVOR I. WILLIAMS

BEES

The Dancing Bees; an account of the Life and Senses of the Honey Bee, *by Karl von Frisch, translated by Dora Ilse. Pp.* 183. *Methuen and Company Limited, London.* 1954. 16*s.* 6*d. net.*

This book is the English translation of its author's *Aus dem Leben der Bienen* (1953). Its clear and persuasive English, free from technical terms, leads the reader on from one remarkable feature of these astonishing insects to another. The title of the book perhaps misleads us a little, for although the dances of the honey bee—which tell the other members of the colony of the discovery of a rich source of food, how far it is away, and the direction in which it lies—are lucidly explained, the book also discusses a great deal more. Topics include the division of labour in the colony, the way a bee smells, the little 'scent bottle' it carries about, the significance of scents, the use of the eyes, the bee's sense of time, its mental capacity and how it finds its way about, the brood, the swarm, the queen and the rearing of the young, the ruthless destruction of unwanted queens, the slaughter of the drones, and the honey bee's enemies and diseases. There is, indeed, little in the life of the honey bee that does not find a place in this book, and many readers will be much interested in the patient and ingenious experiments that have so widely increased our knowledge of these remarkable and valuable insects. For comparison, we are given two chapters on the ants, wasps, bumble bees, and the solitary bees. There are plenty of line illustrations and photographs which really help the reader to understand.

G. LAPAGE

BIRDS OF JAPAN

Shinpen Nihon Chôrui Zusetsu (Illustrated Catalogue of the Birds of Japan), *by Seinosuke Uchida.* (*In Japanese.*) *Pp.* 313, *with* 65 *plates in colour. Sôgensha Publishing Company, Tokyo.* 1950. *Yen* 2200 *net.*

This is a completely revised edition of the *Nihon Chôrui Zusetsu* (an illustrated catalogue of the birds of Japan) by the same author, of which the first, three-volume, edition appeared in 1913–15, and the fourth and latest edition in 1925–7. The present work consists of four parts: the general introduction; illustrations of birds, with descriptions printed on the page opposite each illustration; descriptions of the general characteristics of each order of birds; and indexes of the scientific, Japanese, and English names of birds, together with a bibliography.

The author follows the classification of Ernest Hartert, which is also the classification adopted by the Society of Ornithology of Japan in its publication 'A hand-list of the Japanese birds' (3rd edition, 1942). The author is one of the leading Japanese authorities on ornithology, and the various editions of his works, of which this is the latest, are regarded as standards. The illustrations, of nearly 400 birds, are very well executed and even a reader who cannot read Japanese will have no difficulty, thanks to the excellent indexes, in discovering what kinds of birds live in Japan and what they look like.

K. ENOKI

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

Le Magnétisme des Corps Célestes, Volumes I and II, *by A. Danvillier. Pp. 171 and 161 respectively. Hermann et Cie, Paris.* 1954. *Fcs* 1600 *and* 1500 *respectively.*

BIOLOGY

Sex in Microorganisms, *edited by D. H. Wenrich, Ivey F. Lewis, and John R. Raper. Pp.* 362. *A.A.A.S., Washington, D.C.; Bailey Brothers and Swinfen Limited, London.* 1954. 51*s.* 6*d. net.*

BOTANY

Methods of Surveying and Measuring Vegetation, *by Dorothy Brown. Pp.* 223. *Commonwealth Agricultural Bureaux, Farnham Royal, England.* 1954. 35*s. net.*

CHEMISTRY

Biochemical Society Symposia No. 12—The Chemical Pathology of Animal Pigments. *Pp.* 84. *Cambridge University Press, London.* 1954. 12*s.* 6*d. net.*

The Optical Properties of Organic Compounds, *by Alexander N. Winchell. Pp.* 487. *Academic Press Inc., New York; Academic Books Limited, London.* 1954. $12 *net.*

Outlines of Organic Chemistry (*third edition*), *by E. J. Holmyard. Pp.* 492. *Edward Arnold (Publishers) Limited, London.* 1954. 16*s. net.*

Porphyrins: Their Biological and Chemical Importance, *by A. Vannotti. Pp.* 258 + *xv. Hilger and Watts Limited, London.* 1954. 50*s. net.*

Structure Reports for 1950, Volume 13; *general editor, A. J. C. Wilson. Pp. viii* + 644. *A. Oosthoek's Uitgevers Mij., Utrecht.* 1954. *Fl.* 45 *net.*

The Theory of the Photographic Process (*revised edition*), *by C. E. K. Mees. Pp.* 1133. *The Macmillan Company, New York.* 1954. $21.50 *net.*

Wool: Its Chemistry and Physics, *by Peter Alexander and Robert F. Hudson. Pp.* 404. *Chapman and Hall Limited, London.* 1954. 45*s. net.*

GENERAL

Coal, *by Wilfred Francis. Pp.* 567. *Edward Arnold (Publishers) Limited, London.* 1954. 84*s. net.*

Die Böden Afrikas, *by S. Ju. Schokalskaja.* (*Translated from the Russian.*) *Pp.* 408. *Akademie-Verlag, Berlin.* 1953. *DM.* 29 *net.*

Formation des Continents et Progression de la Vie, *by H. and G. Termier. Pp.* 132. *Masson et Cie, Paris.* 1954. *Fcs* 750 *net.*

Industrial Organization, *by Bimal C. Ghose. Pp.* 250. *Oxford University Press, London.* 1954. 14*s. net.*

Man and Energy, *by A. R. Ubbelohde. Pp.* 247. *Hutchinson's Scientific and Technical Publications, London.* 1954. 18*s. net.*

Reviews of Research on Problems of Utilization of Saline Water. *Pp.* 96. *UNESCO, Paris; Ministry of Education, London.* 1954. 10*s.* 6*d. net.*

Science and the Common Understanding (B.B.C. Reith Lectures, 1953), *by J. Robert Oppenheimer. Pp.* 127. *Oxford University Press, London.* 1954. 10*s.* 6*d. net.*

Techniques of Technical Training, *by H. R. Mills. Pp.* 195. *Cleaver-Hume Press Limited, London.* 1953. 10*s.* 6*d. net.*

HISTORY OF SCIENCE

The Geometry of René Descartes, *translated by D. E. Smith and M. L. Smith. Pp.* 243. *Dover Publications Inc., New York.* 1954. *Paper covers* $1.50 *net; cloth covers* $2.95 *net.*

MATHEMATICS

An Introduction to the Mathematics of Physics, *by J. H. Avery and M. Nelkon. Pp.* 178. *William Heinemann Limited, London.* 1954. 9*s.* 6*d. net.*

Statistical Theory of Extreme Values and Some Practical Applications, *by Emil J. Gumbel. Pp. viii* + 51. *National Bureau of Standards, Washington, D.C.* 1954. 40 *cents net.*

MEDICINE

Atomic Bomb Injuries, *edited by Nobuo Kusano. Pp.* 112. *The Tsukiji Shokan Company, Tokyo.* 1953. $8 *net.*

Documenta Ophthalmologica, Volumes VII–VIII. *Pp.* 758. *Dr W. Junk, The Hague.* 1954. £12 *net.*

METALLURGY

Rare Metals Handbook, *edited by Clifford A. Hampel. Pp. xiii* + 657. *Chapman and Hall, Limited, London; Reinhold Publishing Corporation, New York.* 1954. 96*s. net.*

PHYSICS

The Aim and Structure of Physical Theory, *by Pierre Duhem. Pp. xiii* + 344. *Princeton University Press, Princeton; Geoffrey Cumberlege, London.* 1954. 48*s. net.*

Chaleur, Thermodynamique, États de la Matière, *by P. Fleury and J. P. Mathieu. Pp.* 523. *Editions Eyrolles, Paris.* 1954. *Fcs* 3400 *net.*

Elements of Statistical Mechanics, *by D. ter Haar. Pp.* 468. *Rinehart and Company Inc., New York.* 1954. $8.50 *net.*

Journal of Nuclear Energy, Volume 1, Number 1. *Pp.* 91. *Pergamon Press Limited, London.* 1954. *Quarterly;* 90*s. net per volume* (70*s. net for private subscribers*).

Nuclear Species, *by H. E. Huntley. Pp. xix* + 193. *Macmillan and Company Limited, London.* 1954. 21*s. net.*

On the Sensations of Tone, *by Herman L. F. Helmholtz, with a new introduction by Henry Margenau. Pp. xix* + 576. *Dover Publications Inc., New York.* 1954. $4.95 *net.*

Rocket Exploration of the Upper Atmosphere, *edited by R. L. F. Boyd and M. J. Seaton, in consultation with H. S. W. Massey. Pp.* 376. *Pergamon Press Limited, London.* 1954. 75*s. net.*

TECHNOLOGY

Modern Chemical Processes, *by the editors of 'Industrial and Engineering Chemistry'. Pp.* 276. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 40*s. net.*

Significance of Properties of Petroleum Products, *edited by George Sell. Pp.* 74. *The Institute of Petroleum, London.* 1954. 7*s.* 6*d. net.*

Statistical Analysis in Chemistry and the Chemical Industry, *by Carl A. Bennett and Norman L. Franklin. Pp. xvi* + 724. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 58*s. net.*

ZOOLOGY

An Outline of Developmental Physiology, *by C. P. Raven. Pp.* 216. *Pergamon Press Limited, London.* 1954. 17*s.* 6*d. net.*

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Was born in 1902 and was educated at Birkenhead School and at Corpus Christi College, Oxford, where he read zoology and became specially interested in the sense organs of insects. He then worked under the late Professor H. S. Raper in the Physiological Laboratory, Manchester University, where he took up tissue culture and the study of growth. This study he continued in the Physiological Laboratory, Cambridge, where in 1929 he was made Lecturer in Histology, becoming Reader in 1948; he became a Fellow of Clare College in 1936. For the last ten years he has been interested in structural properties of the eye, particularly in relation to the problem of colour vision. He is the author of a small monograph on 'Tissue Culture' and of 'Retinal Structure and Colour Vision.'

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Was born in 1900 at Küsnacht/Zürich. He studied natural sciences at the Swiss Federal Institute of Technology, Zürich, and optics at Jena. He was a pioneer in submicroscopic morphology long before the electron microscope became a tool for biologists; methods such as the application of polarized light and X-rays were used to get information on submicroscopic structures. The electron microscope has confirmed the existence of these structures, and shows much more detail. He is now director of the Laboratories of General Botany and Electron Microscopy of the Swiss Federal Institute of Technology, Zürich.

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